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Chuang et al.

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(54) **METHOD OF FORMING VERTICAL COUPLING STRUCTURE FOR NON-ADJACENT RESONATORS**

(75) Inventors: **Chia-Cheng Chuang**, Kaohsiung (TW); **Ruey-Beei Wu**, Taipei (TW); **Tze-Min Shen**, Chiayi (TW)

(73) Assignees: **Industrial Technology Research Institute**, Hsinchu (TW); **National Taiwan University**, Taipei (TW)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
H04R 31/00 (2006.01)

(52) **U.S. Cl.** **29/594**; 29/609.1; 216/62; 216/63; 216/66; 181/171; 181/172; 310/321; 310/328; 310/330; 310/331; 310/332; 333/202; 333/208; 333/212; 381/396; 381/398

(58) **Field of Classification Search** 29/594, 29/609.1; 216/62, 63, 66; 181/171, 172; 310/321, 328, 330–332; 333/202, 208, 212; 381/396, 398

See application file for complete search history.

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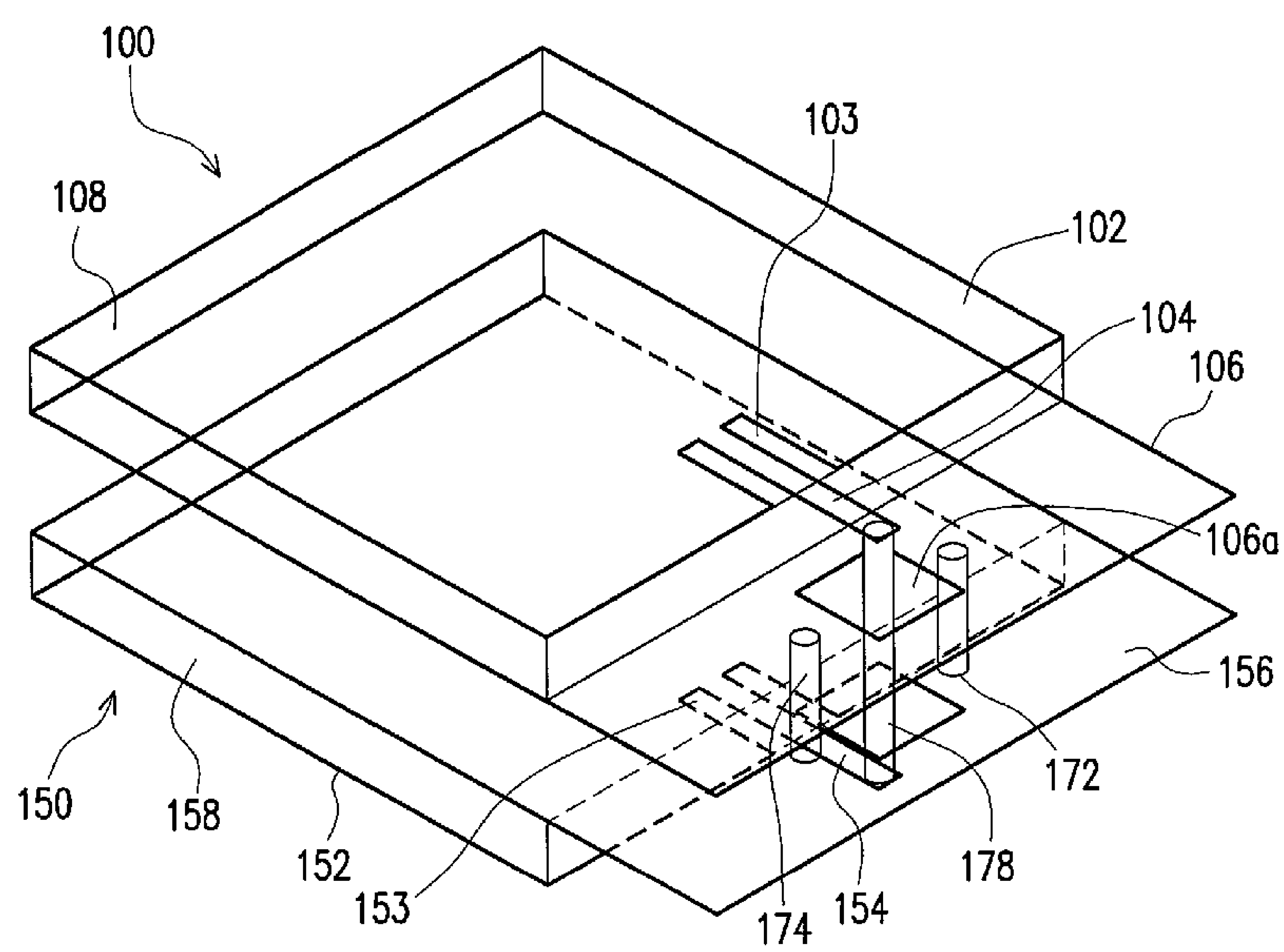
Primary Examiner—Paul D Kim
(74) *Attorney, Agent, or Firm*—Jianq Chyun IP Office

(57) **ABSTRACT**

A method for forming a vertical coupling structure for non-adjacent resonators is provided to have a first and a second resonators, a dielectric material layer, a first and a second high-frequency transmission lines and at least one via pole. The first and the second resonators respectively have a first and a second opposite metal surfaces. The dielectric material layer is disposed between the opposite second metal surfaces of the first and the second resonators. The first and the second transmission lines are respectively arranged at sides of the first metal surfaces of the first resonator and the second resonator. The first high-frequency transmission line is vertically connected to the second high-frequency transmission line by the via pole.

10 Claims, 14 Drawing Sheets



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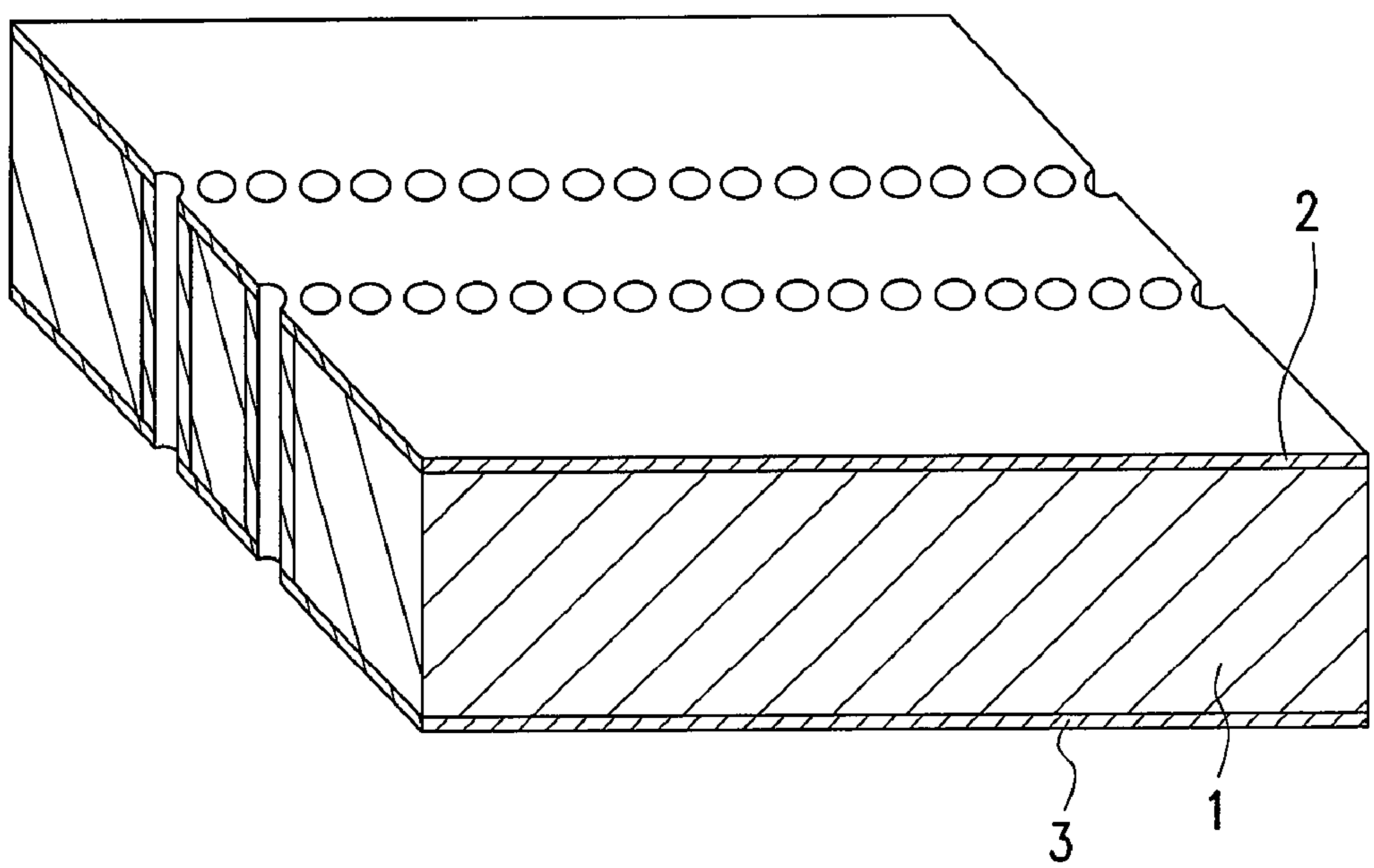

FIG. 1 (PRIOR ART)

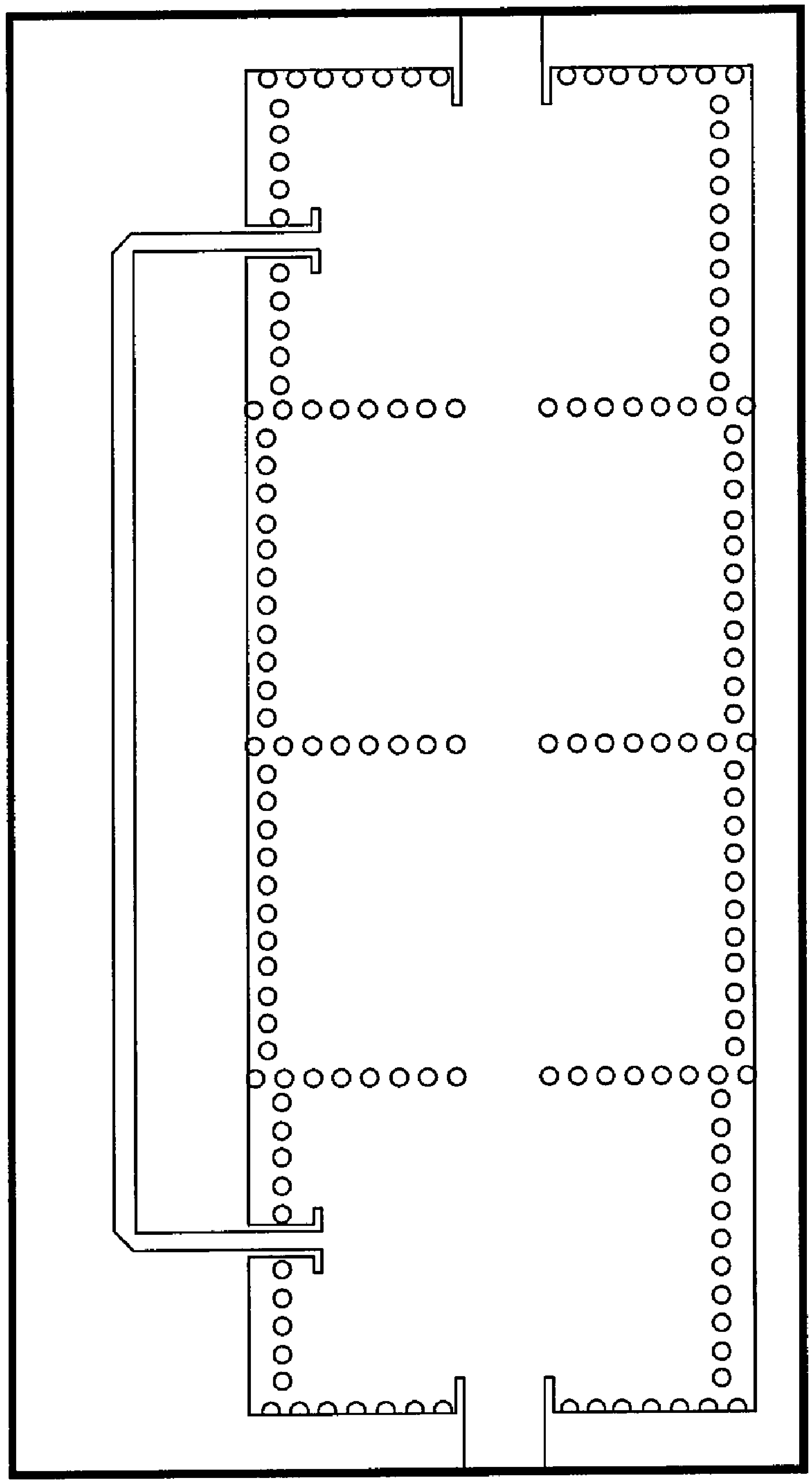

FIG. 2 (PRIOR ART)

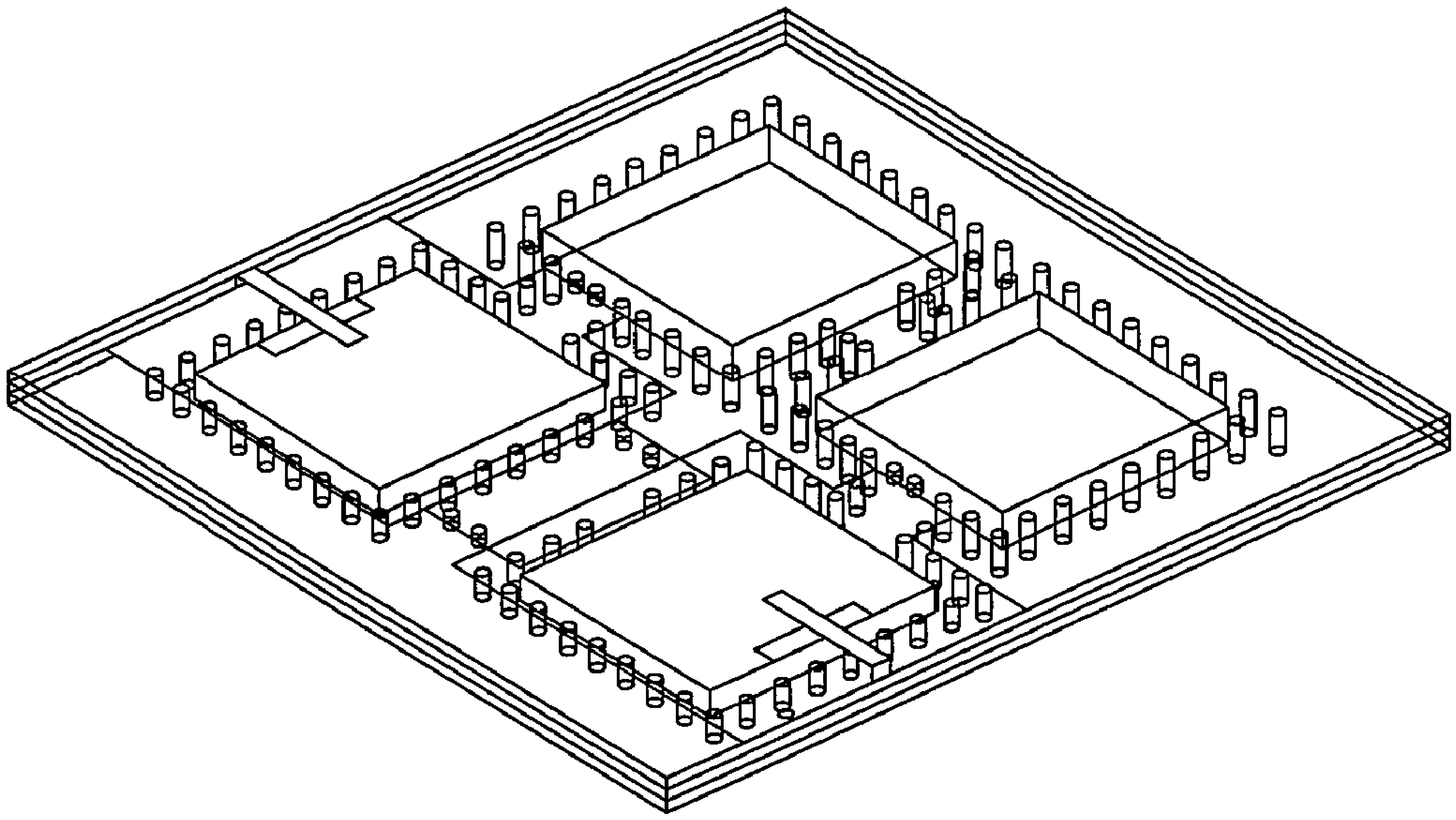

FIG. 3 (PRIOR ART)

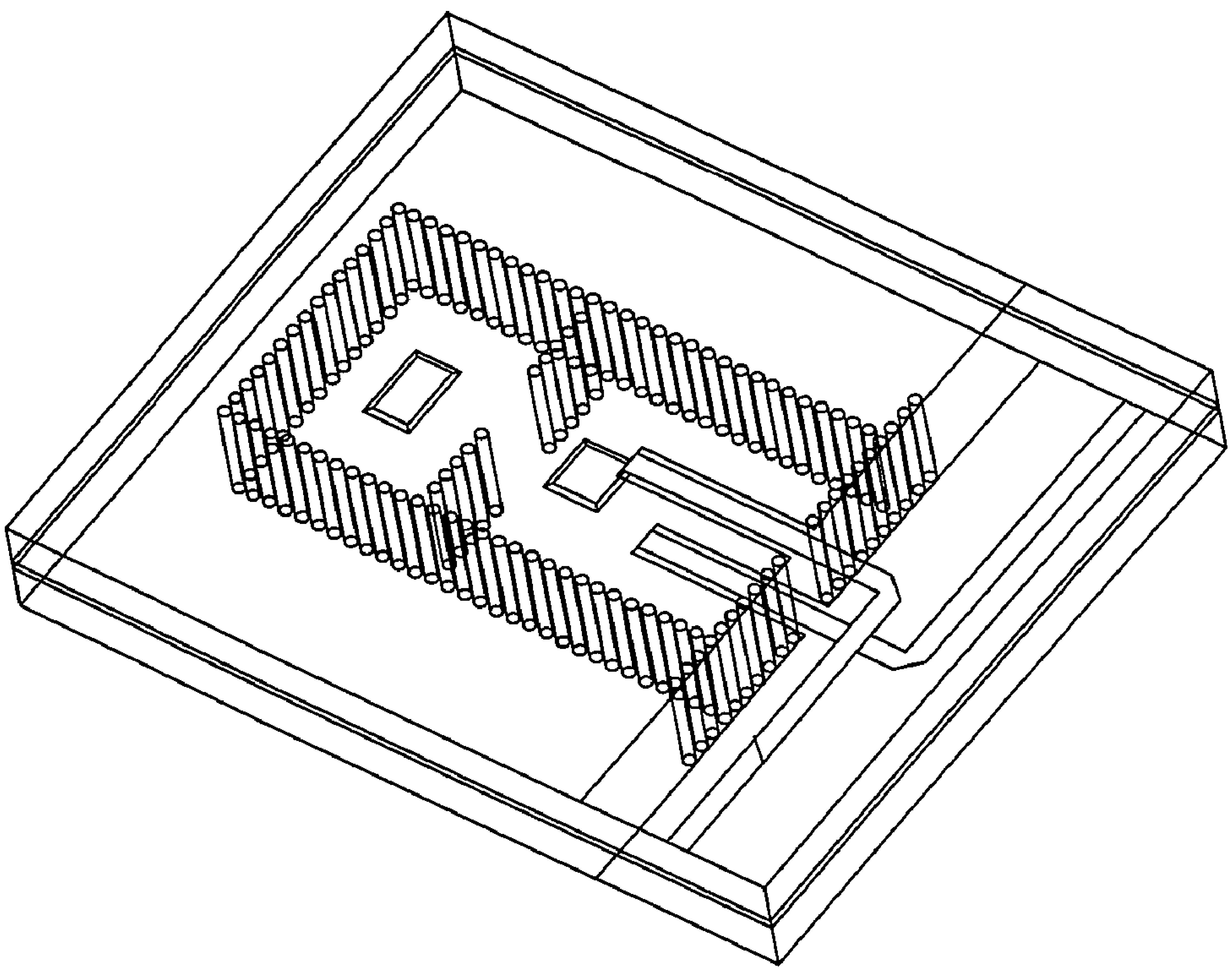

FIG. 4 (PRIOR ART)

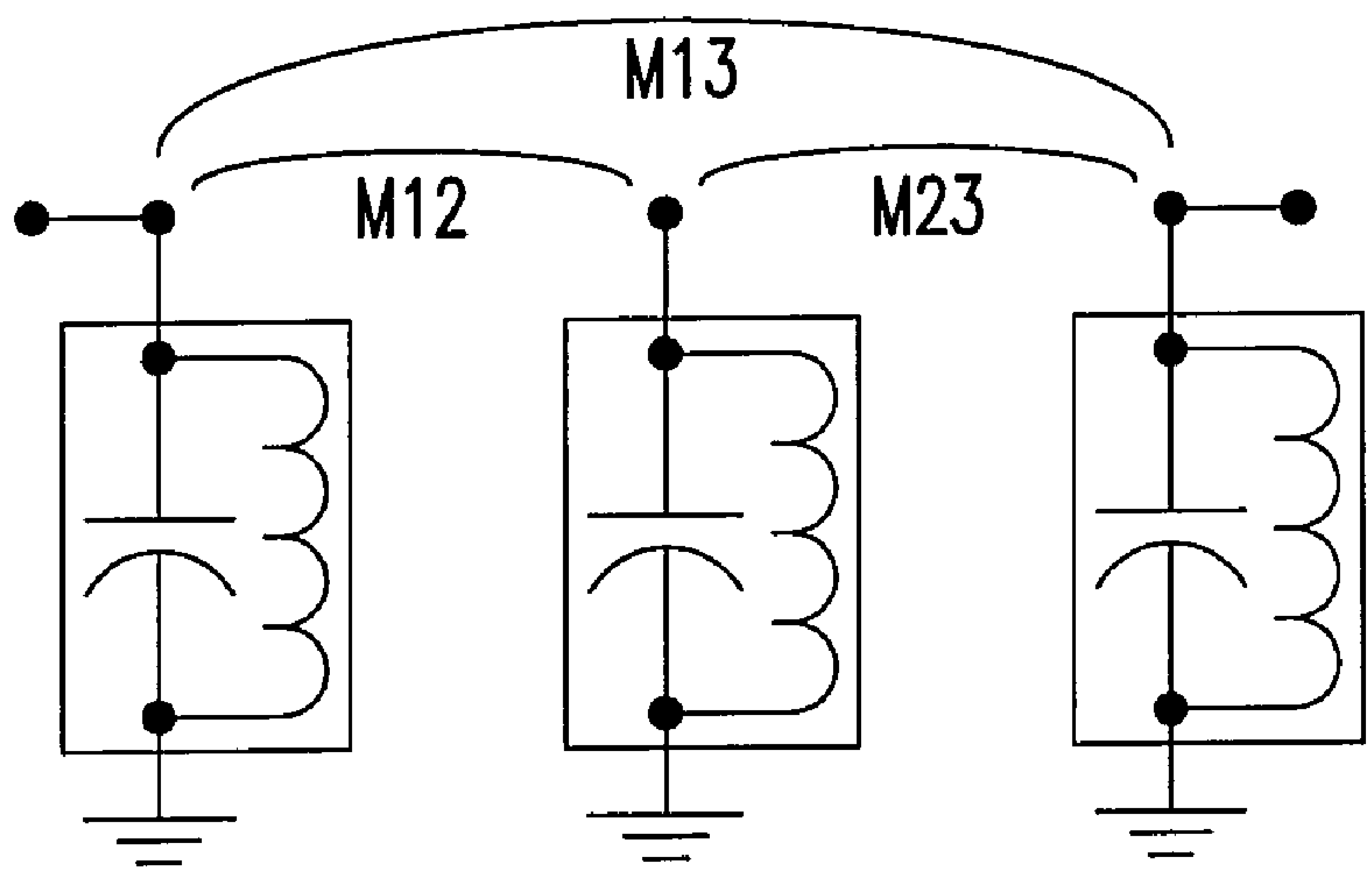

FIG. 5

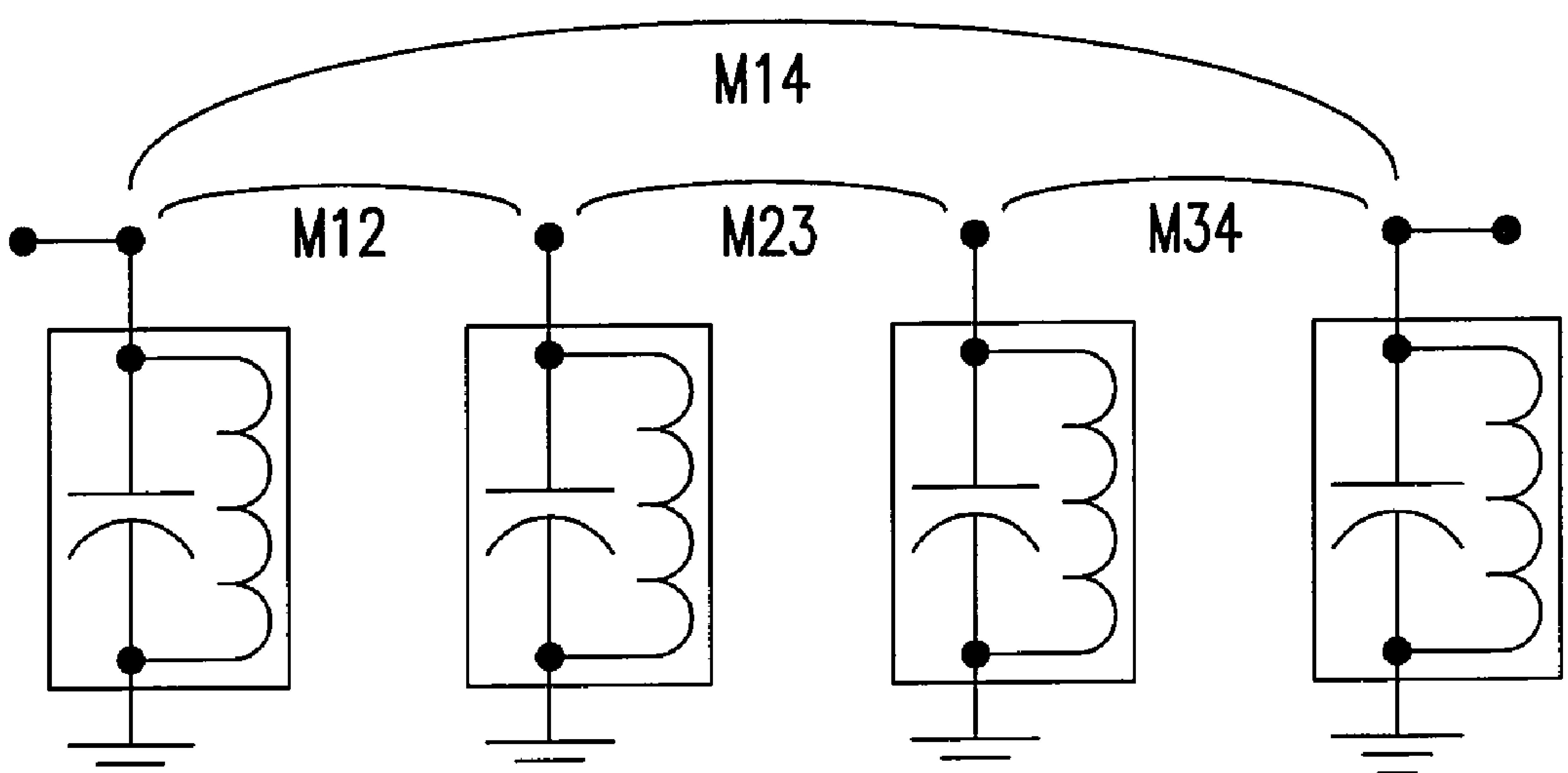

FIG. 6

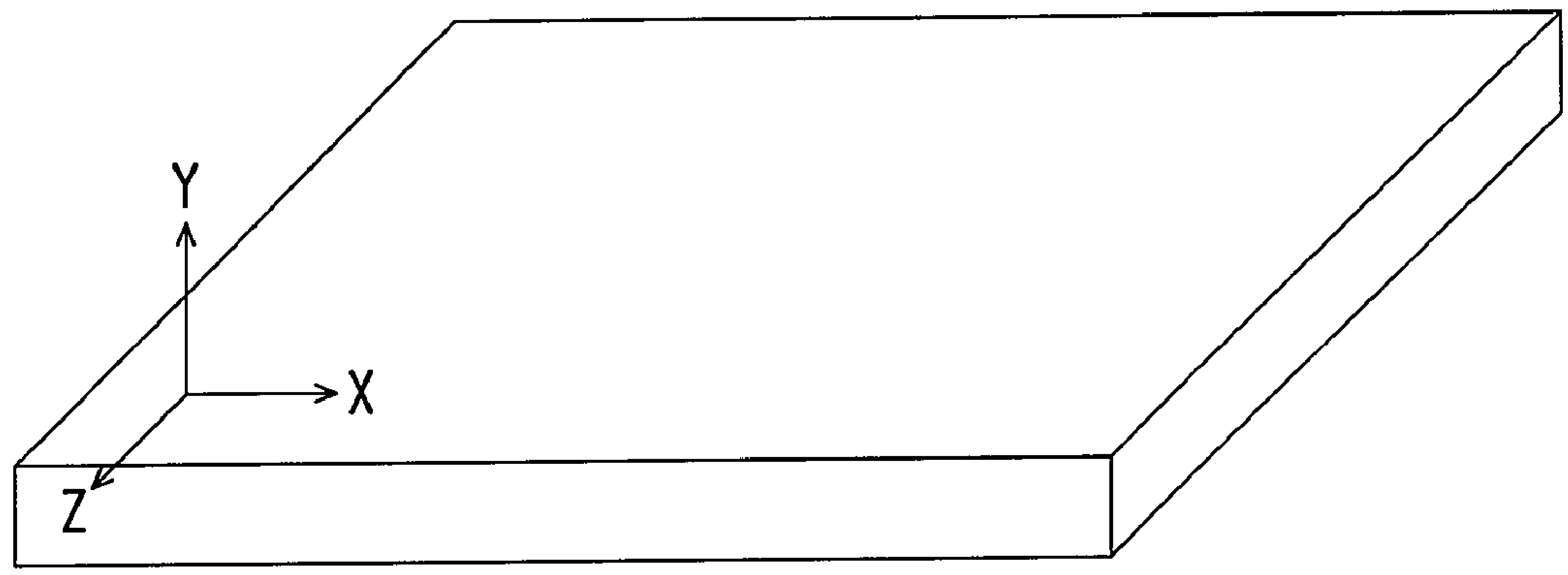
Y
X
Z

FIG. 7

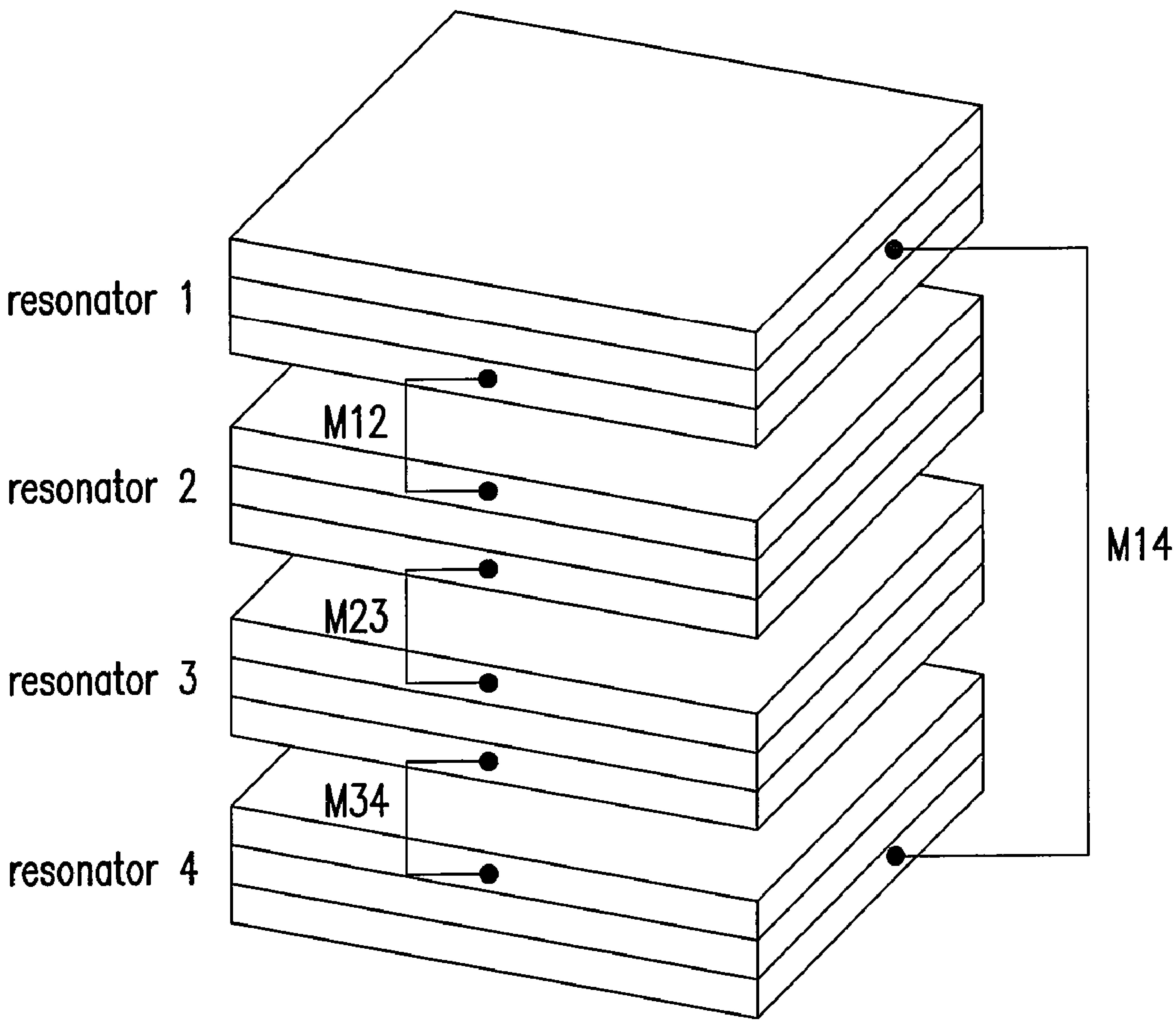
resonator 1
M12
resonator 2
M23
resonator 3
M34
resonator 4
M14

FIG. 8

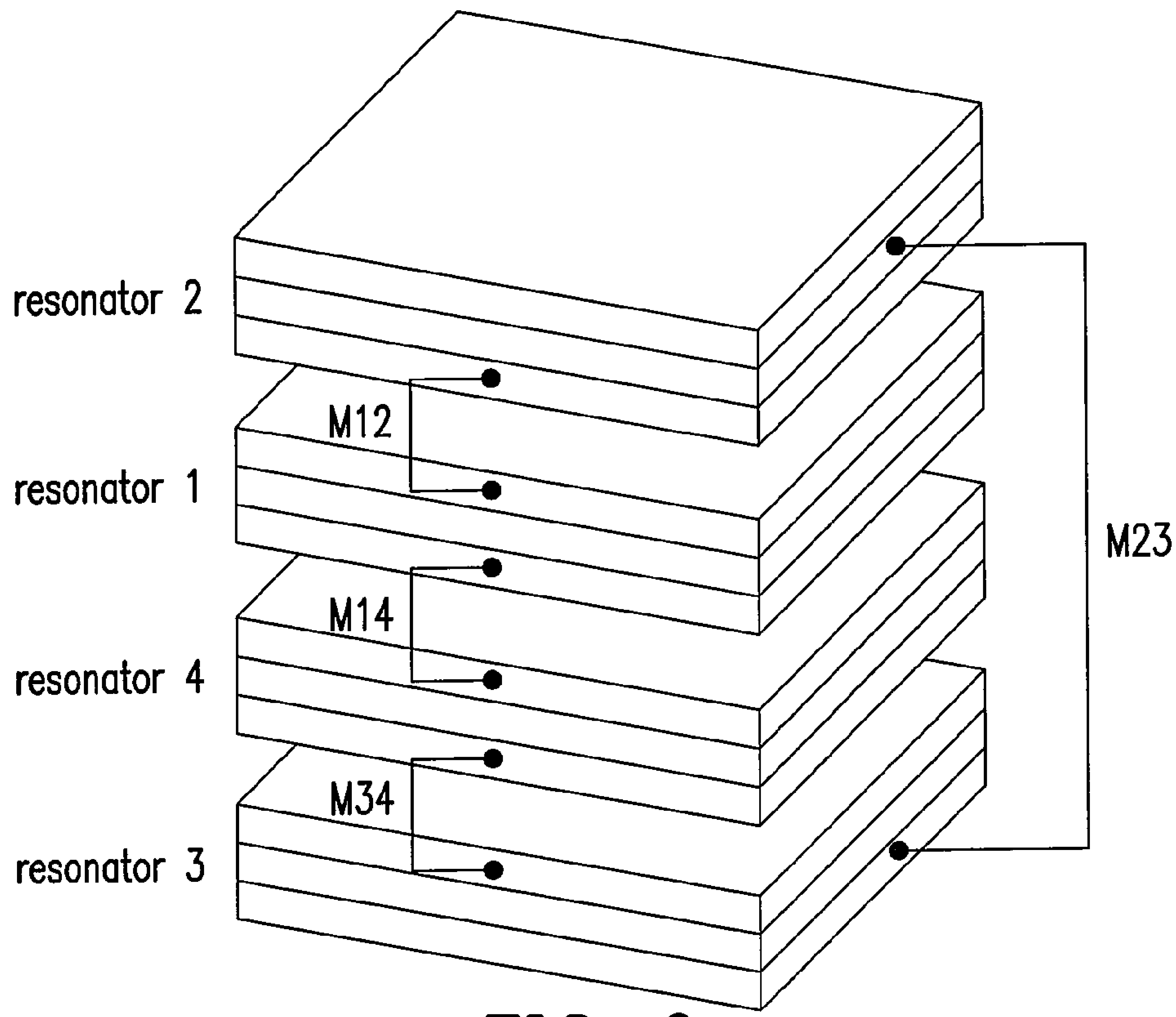
resonator 2
resonator 1
resonator 4
resonator 3
M12
M14
M34
M23

FIG. 9

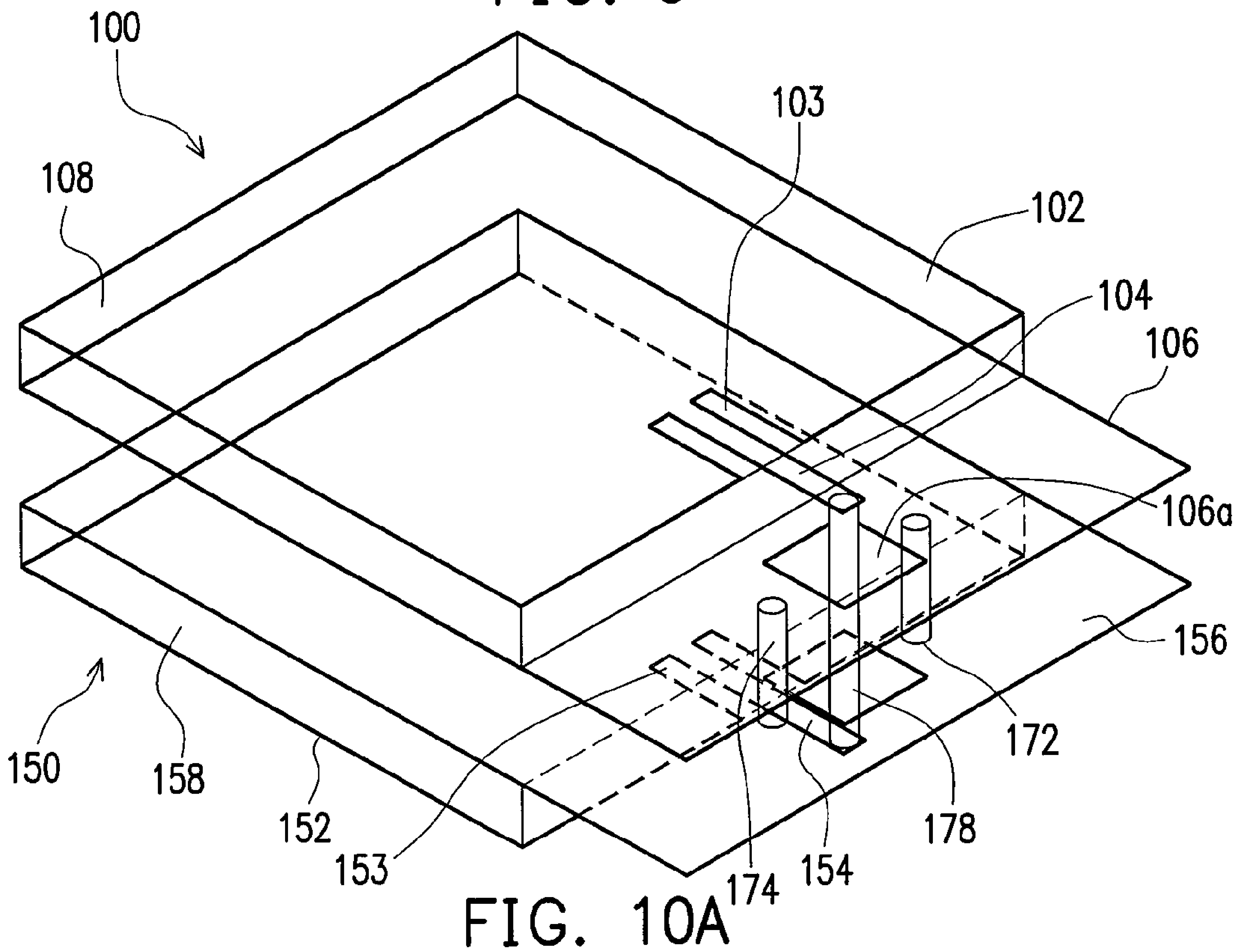
100
108
103
102
104
106
106a
156
172
178
154
174
153
152
158
150

FIG. 10A

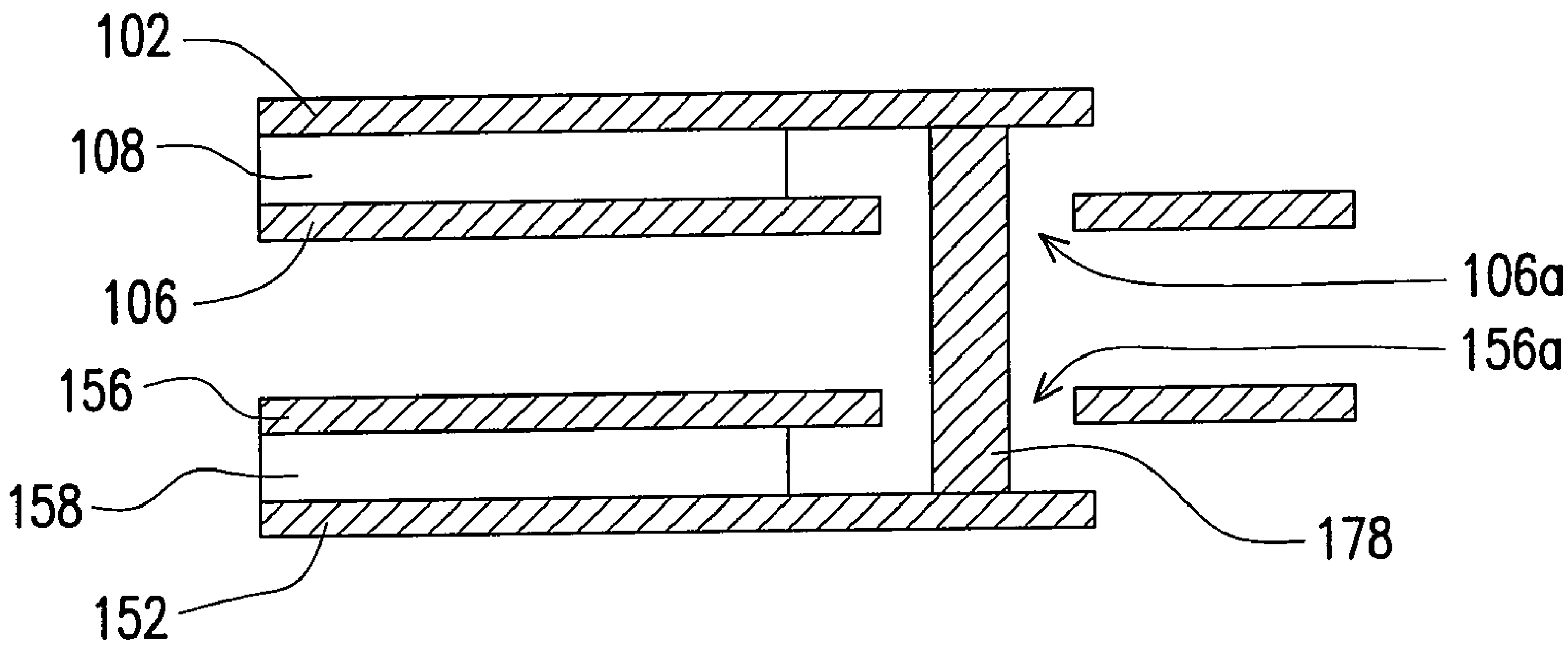

FIG. 10B

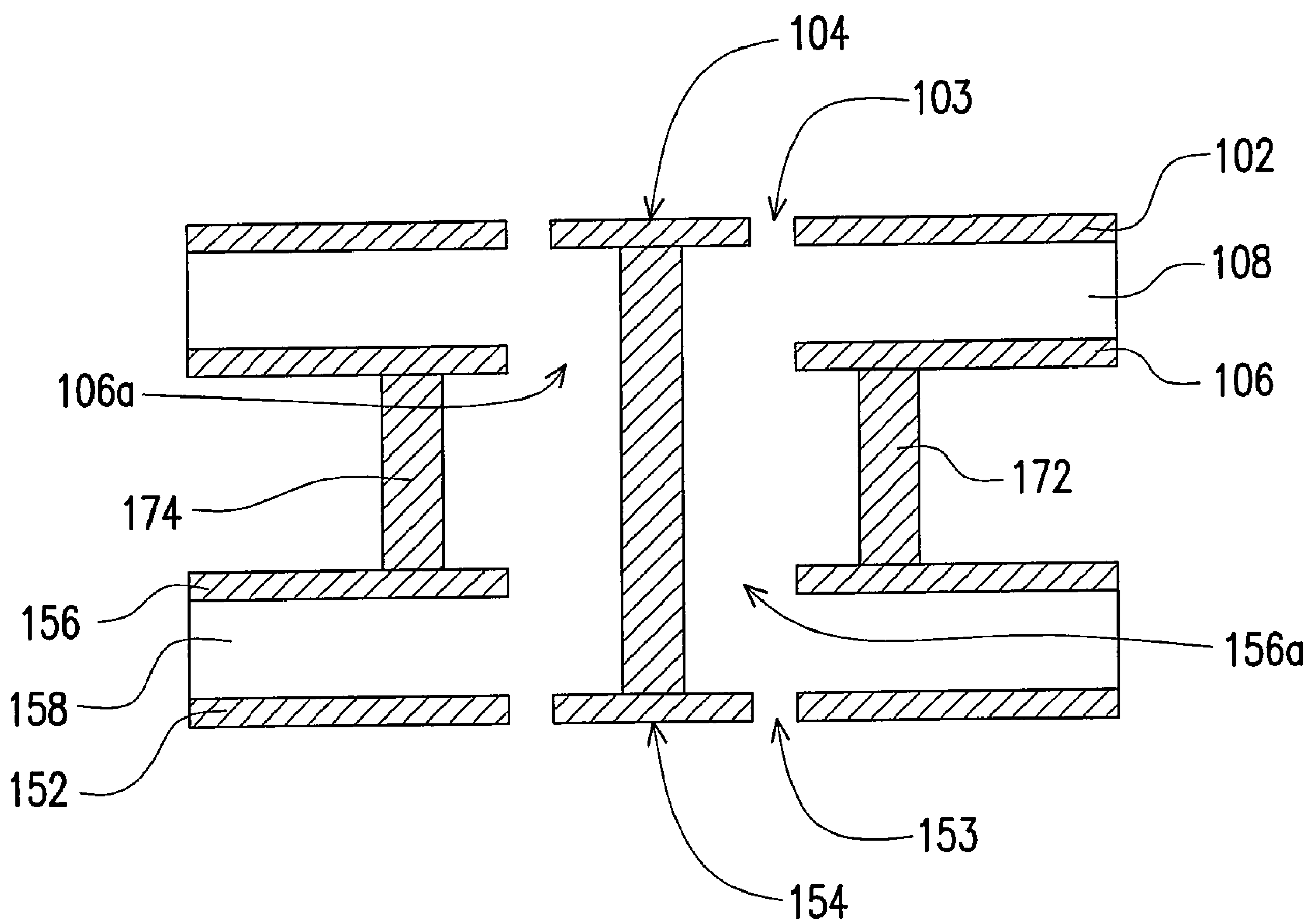

FIG. 10C

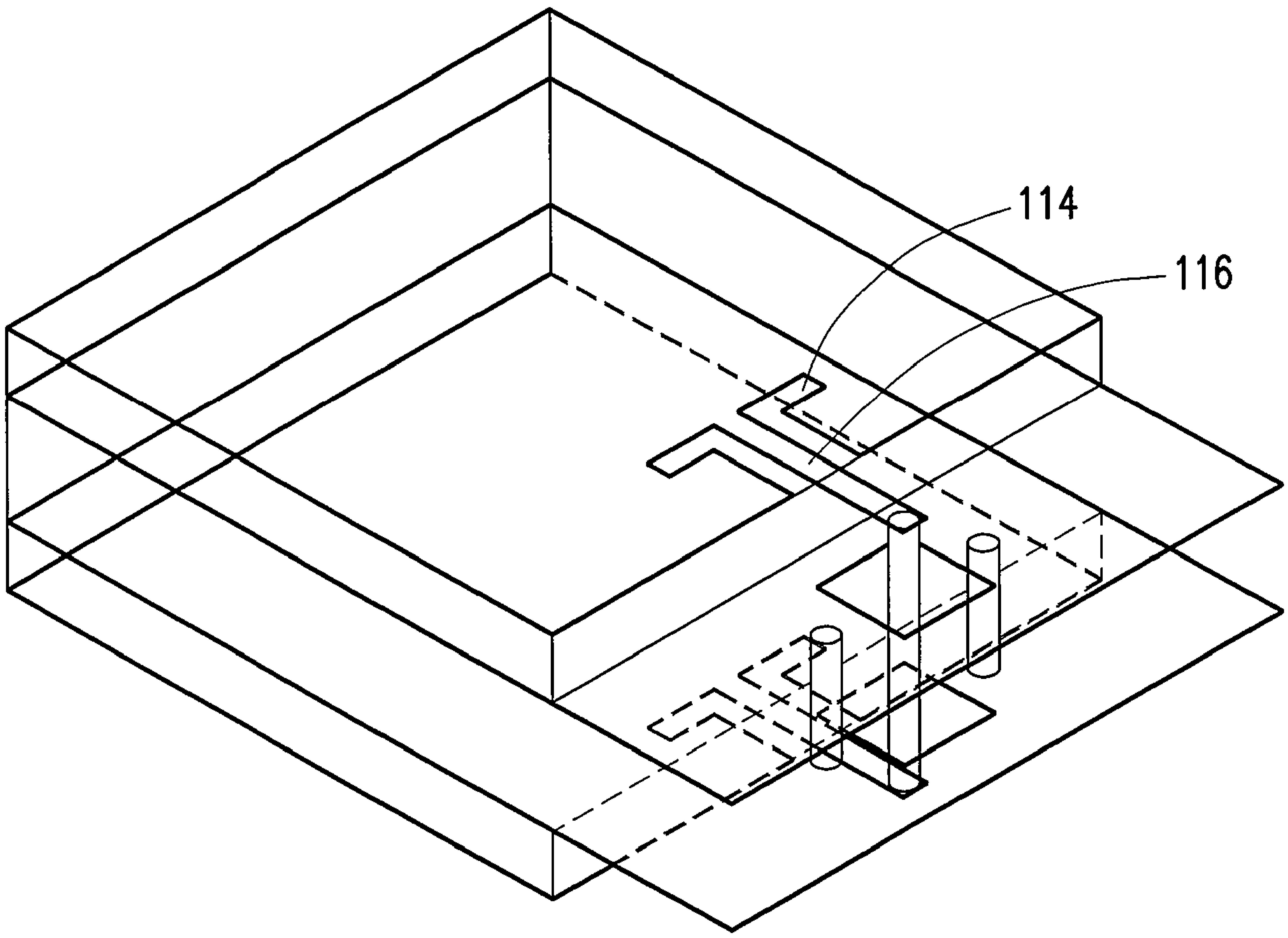

FIG. 11

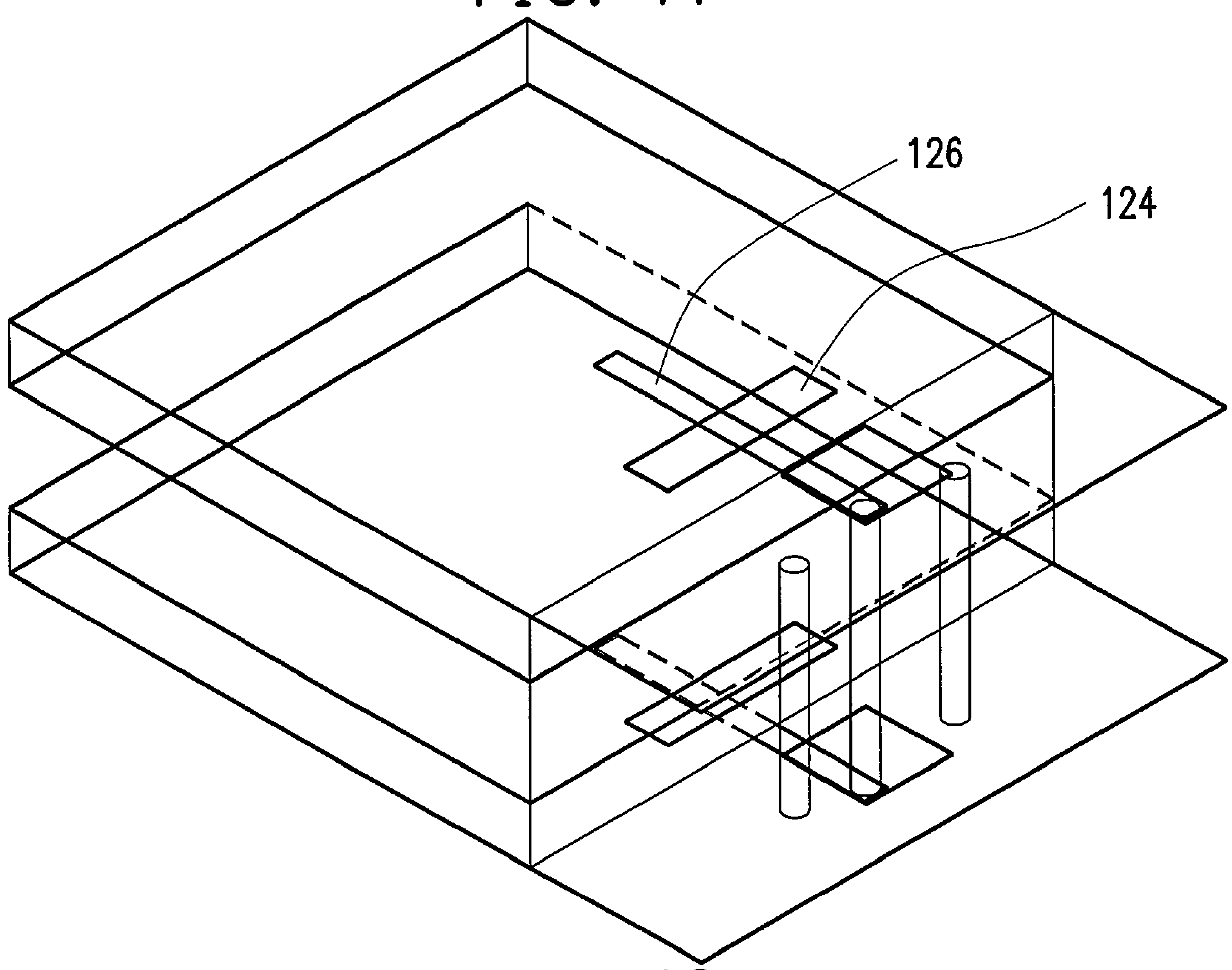

FIG. 12

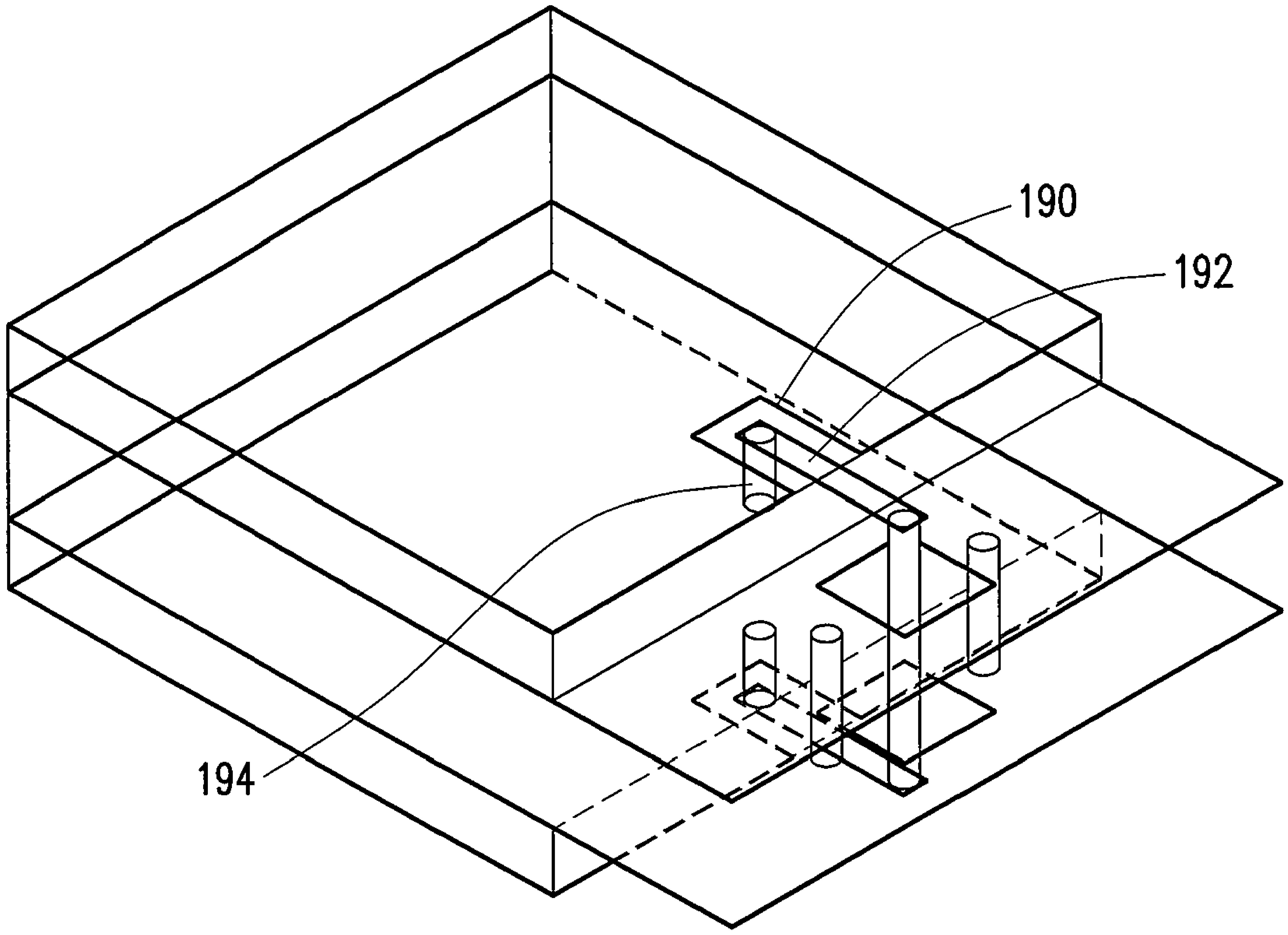

FIG. 13

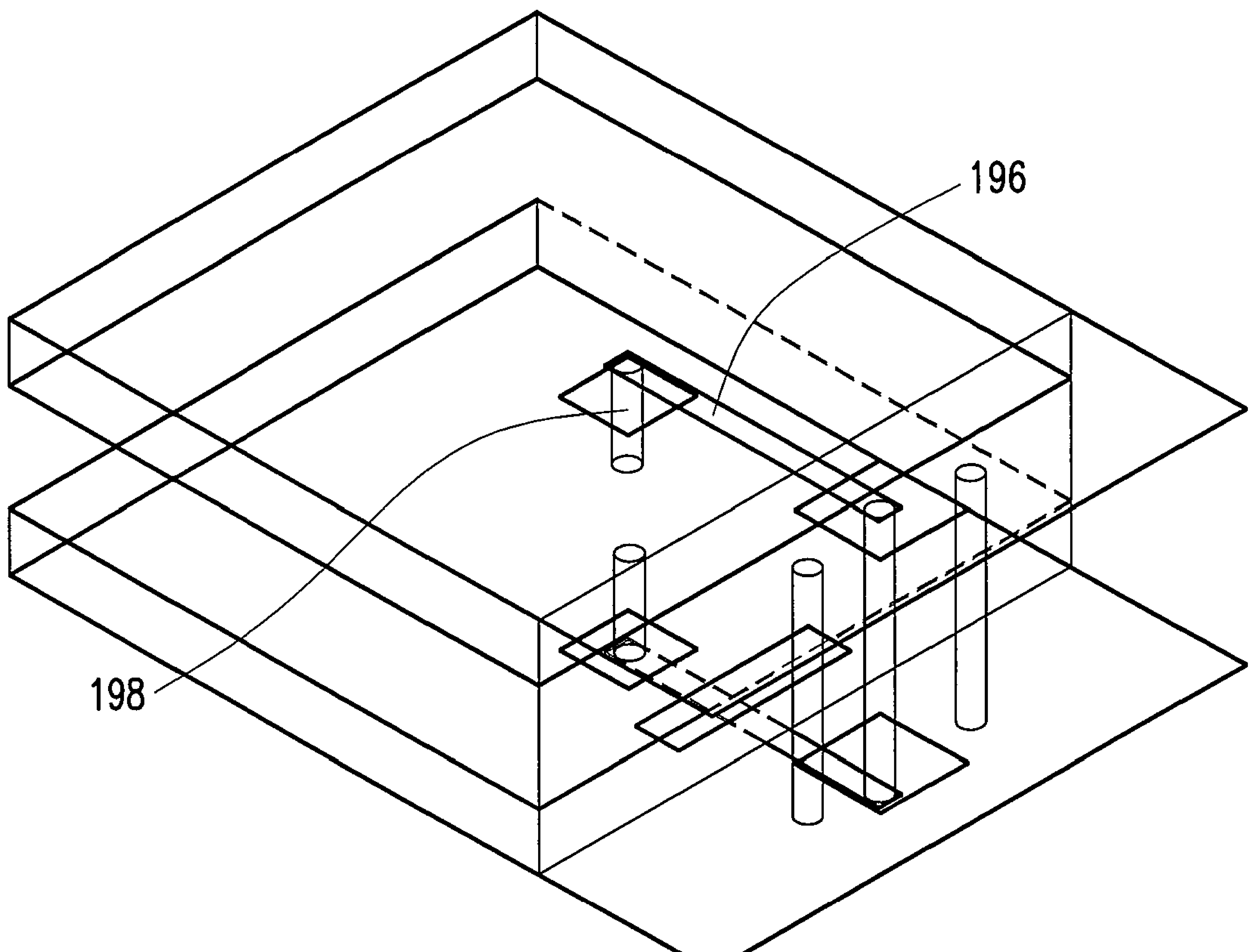

FIG. 14

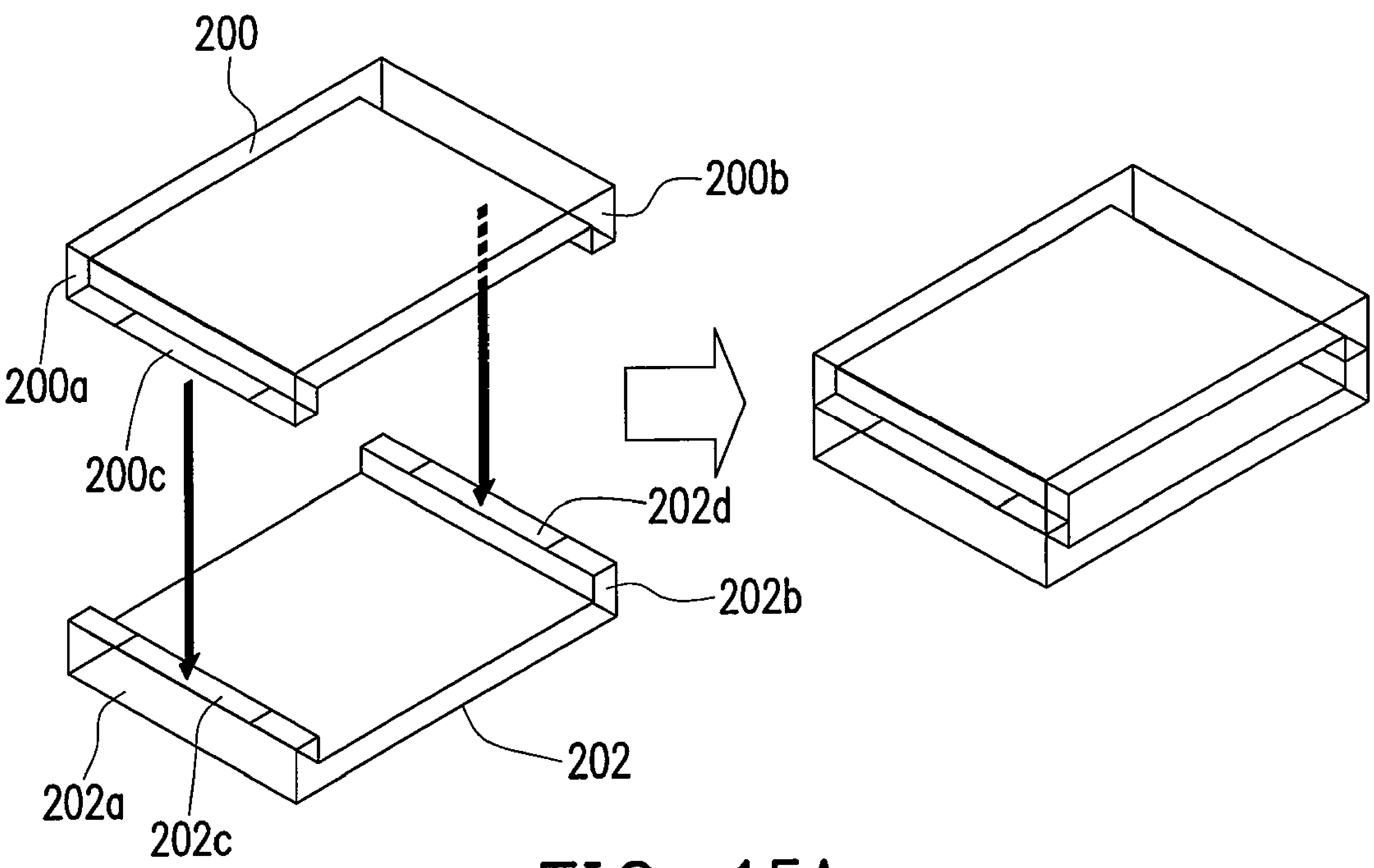

FIG. 15A

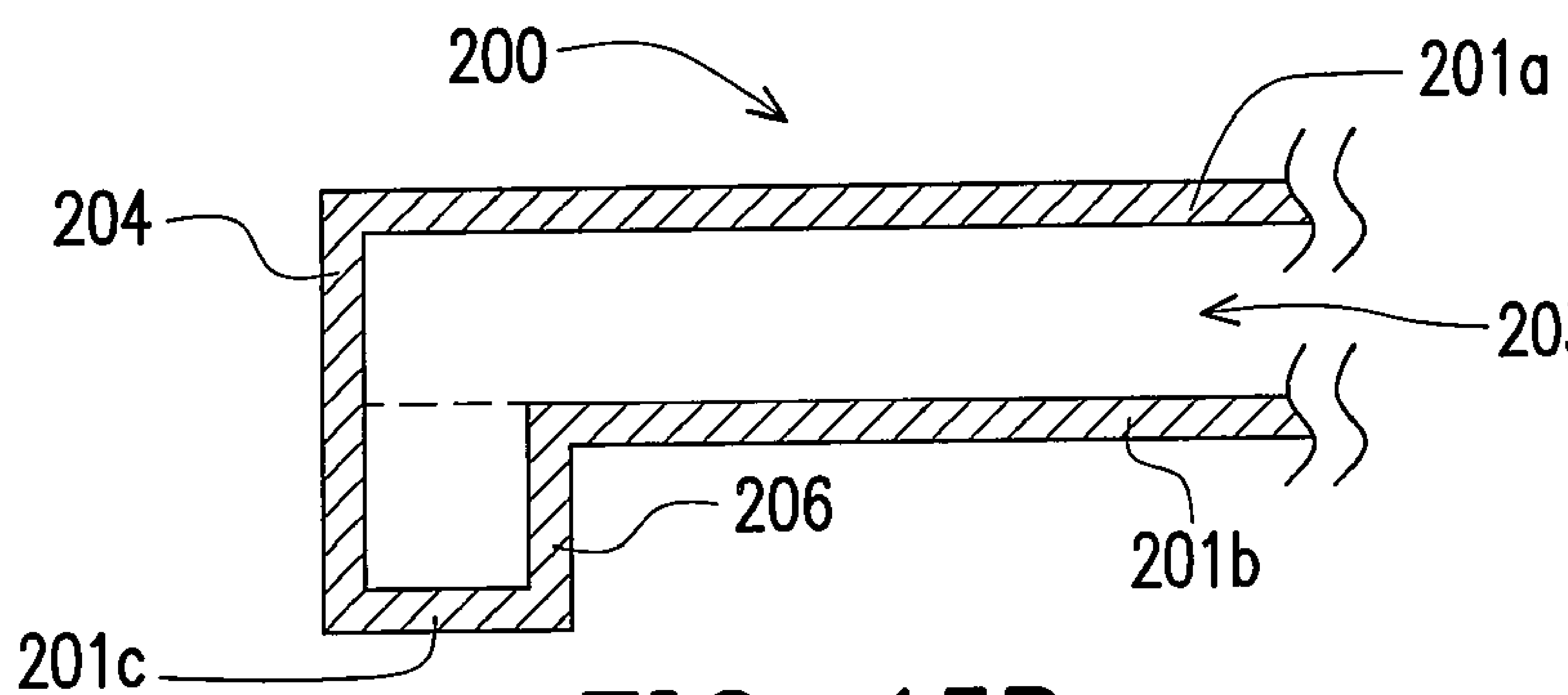

FIG. 15B

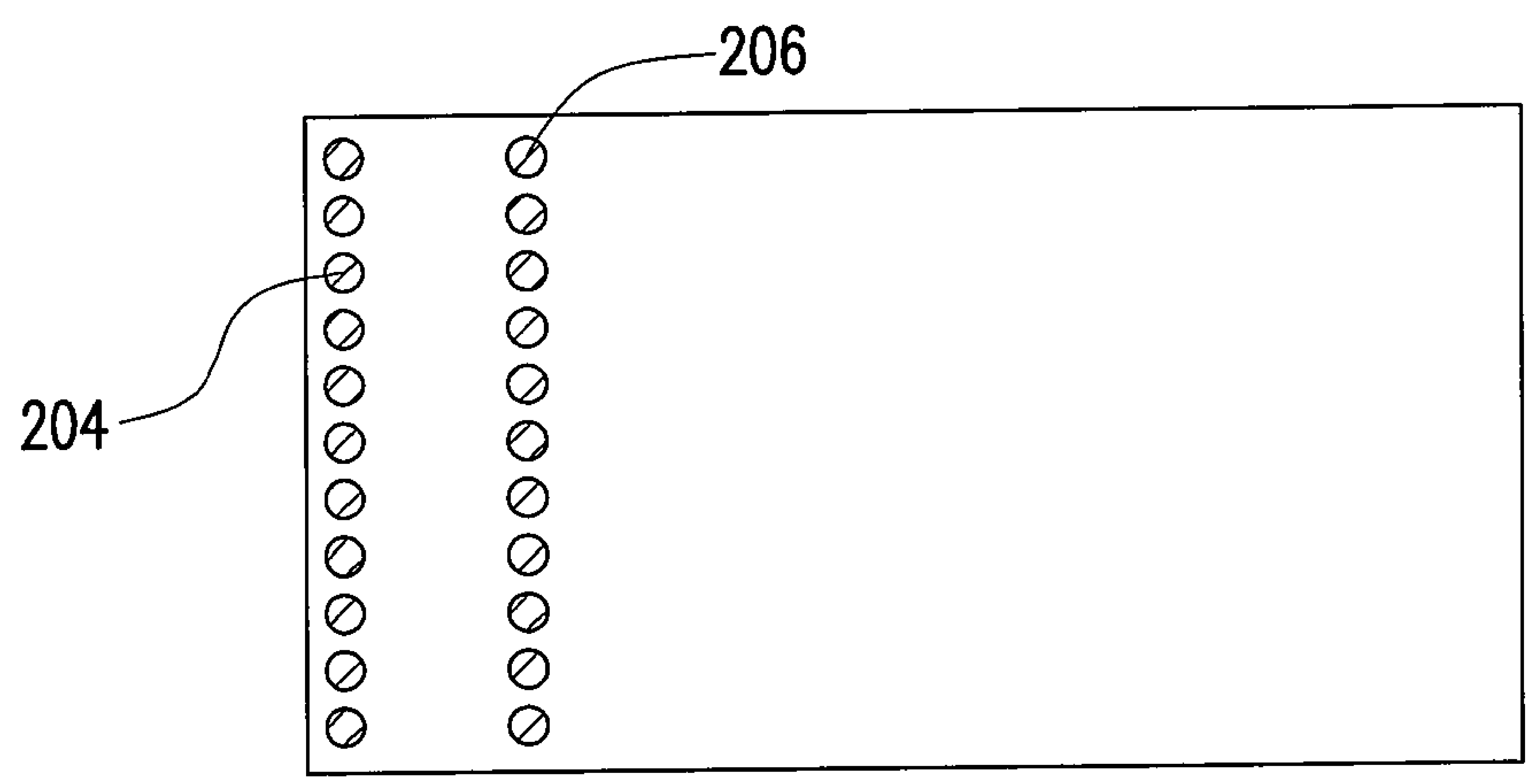

FIG. 15C

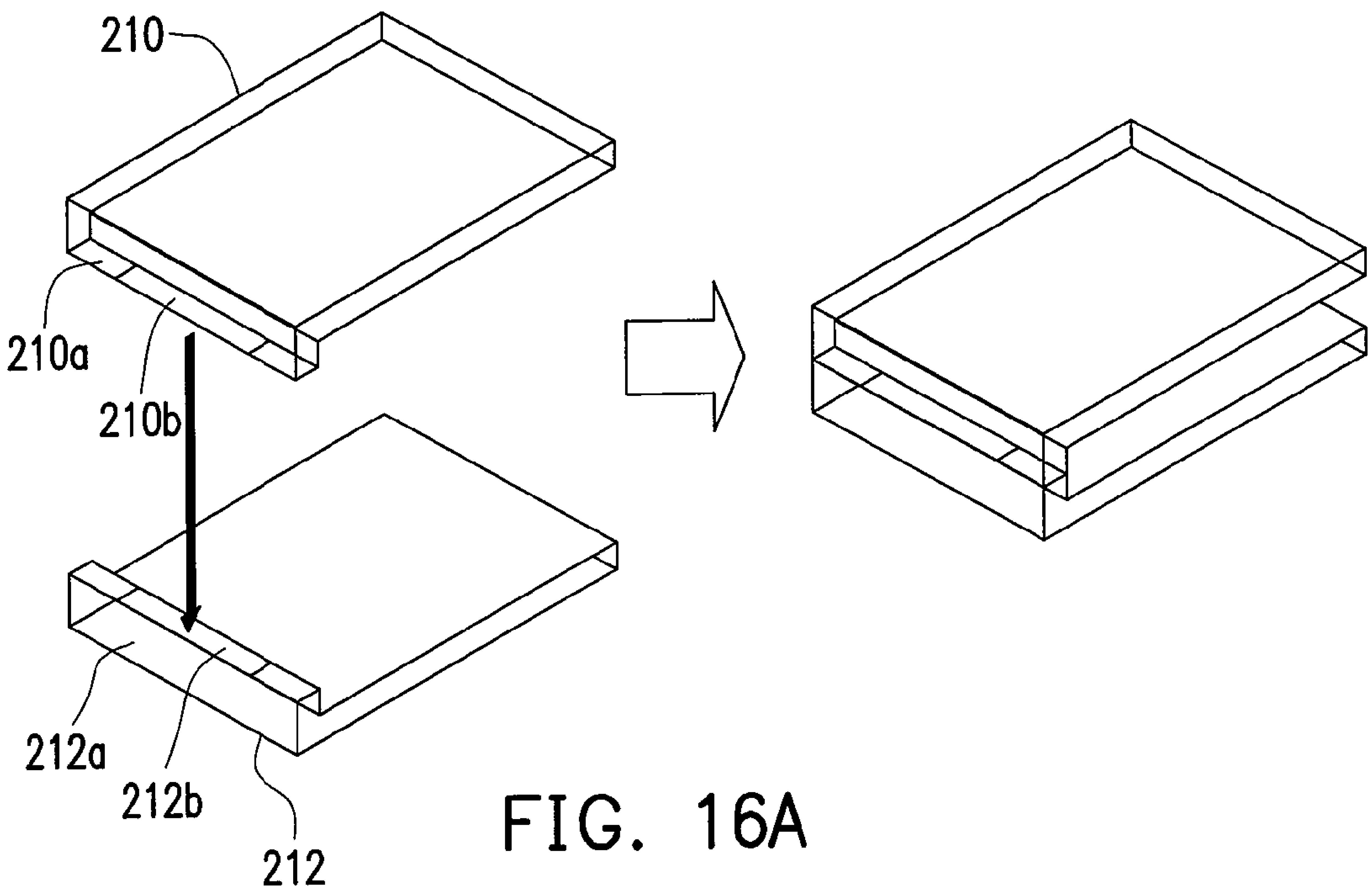

FIG. 16A

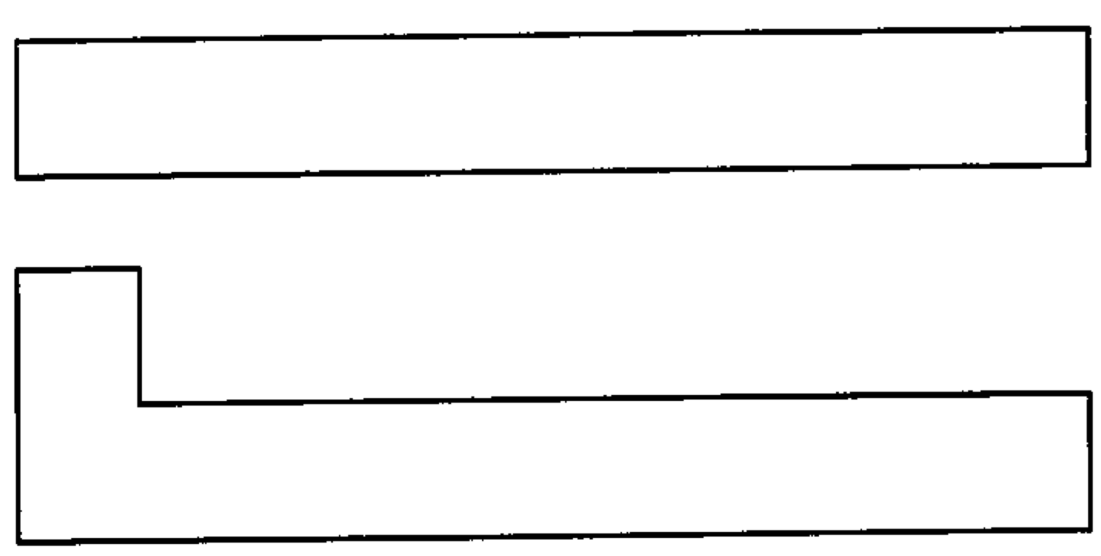

FIG. 16B

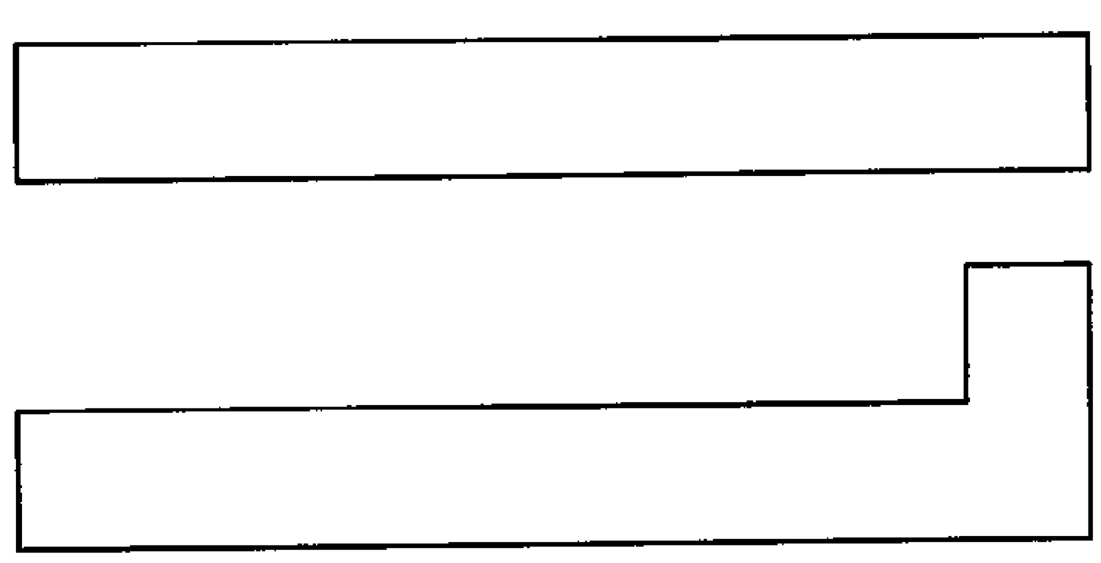

FIG. 16C

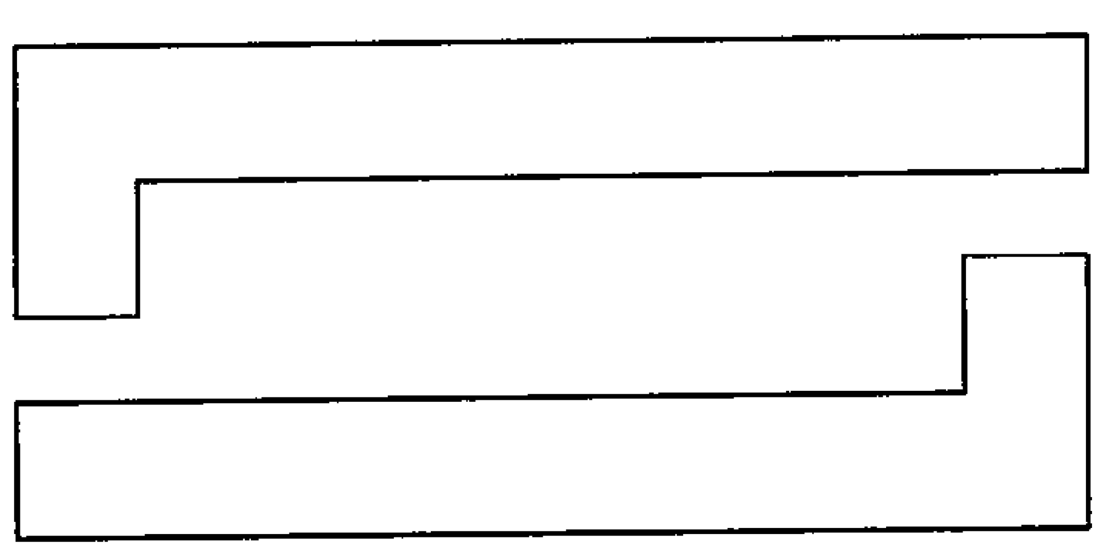

FIG. 16D

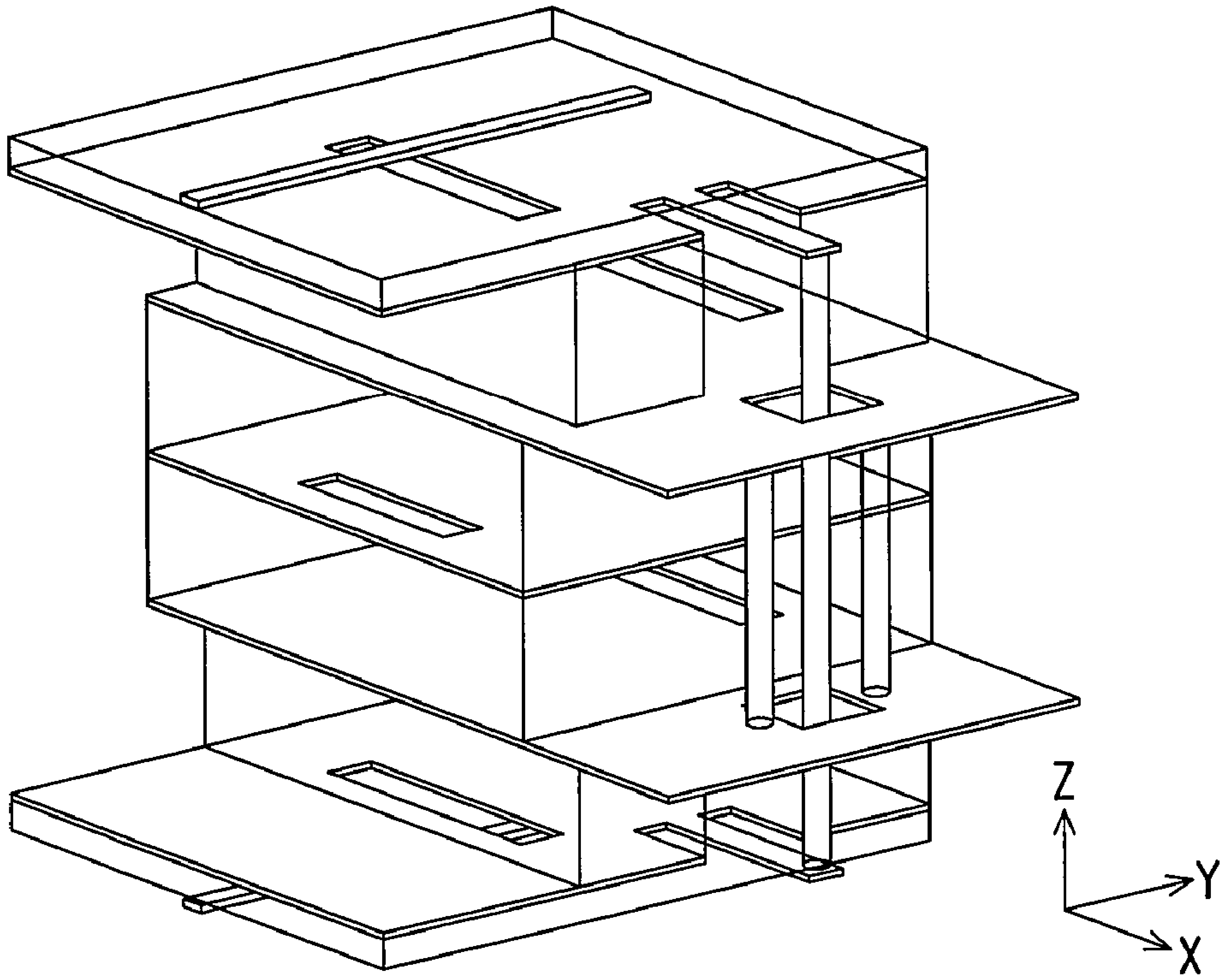
Z
Y
X

FIG. 17

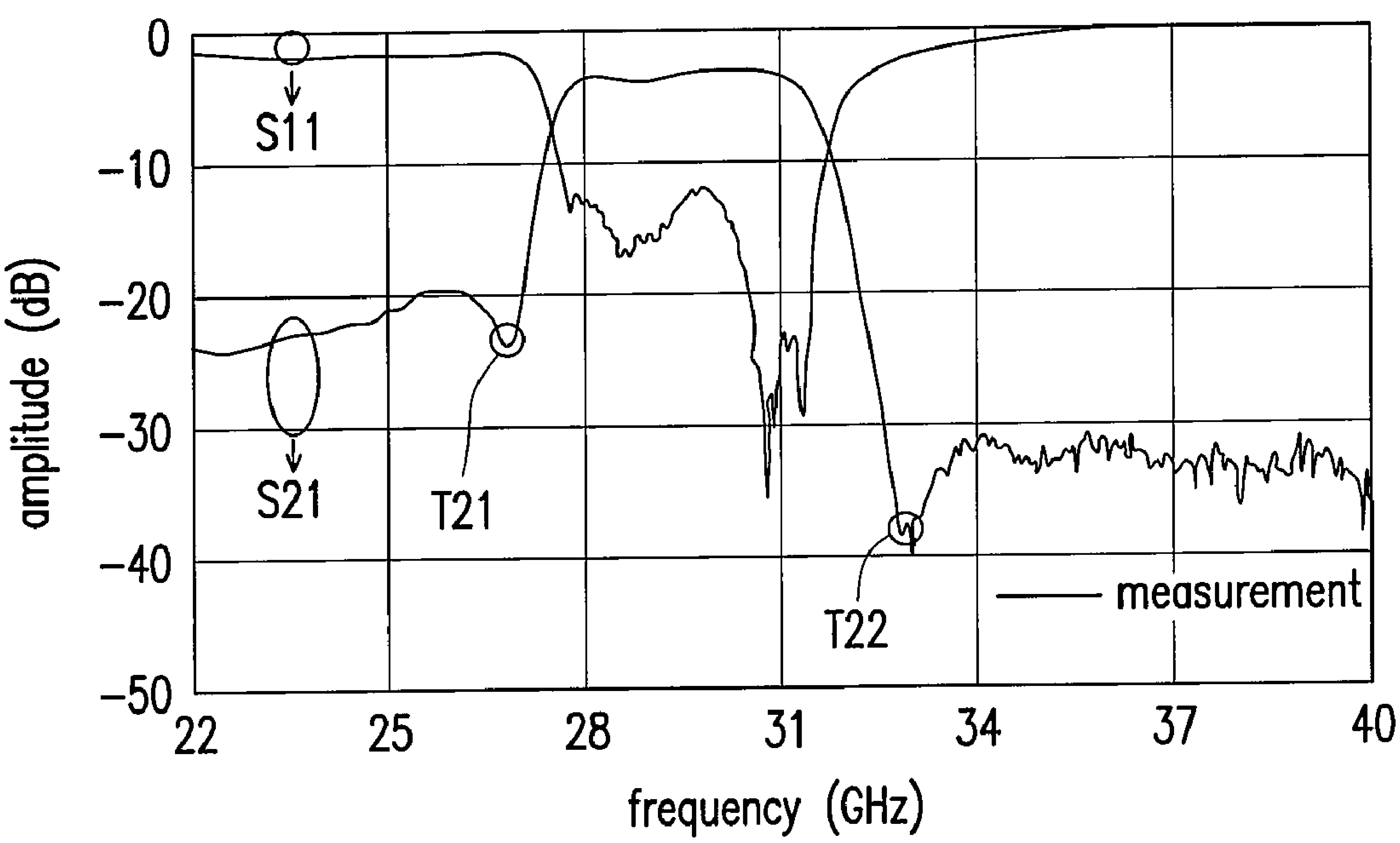
0
-10
-20
-30
-40
-50
22
25
28
31
34
37
40
amplitude (dB)
frequency (GHz)
S11
S21
T21
T22
measurement

FIG. 18

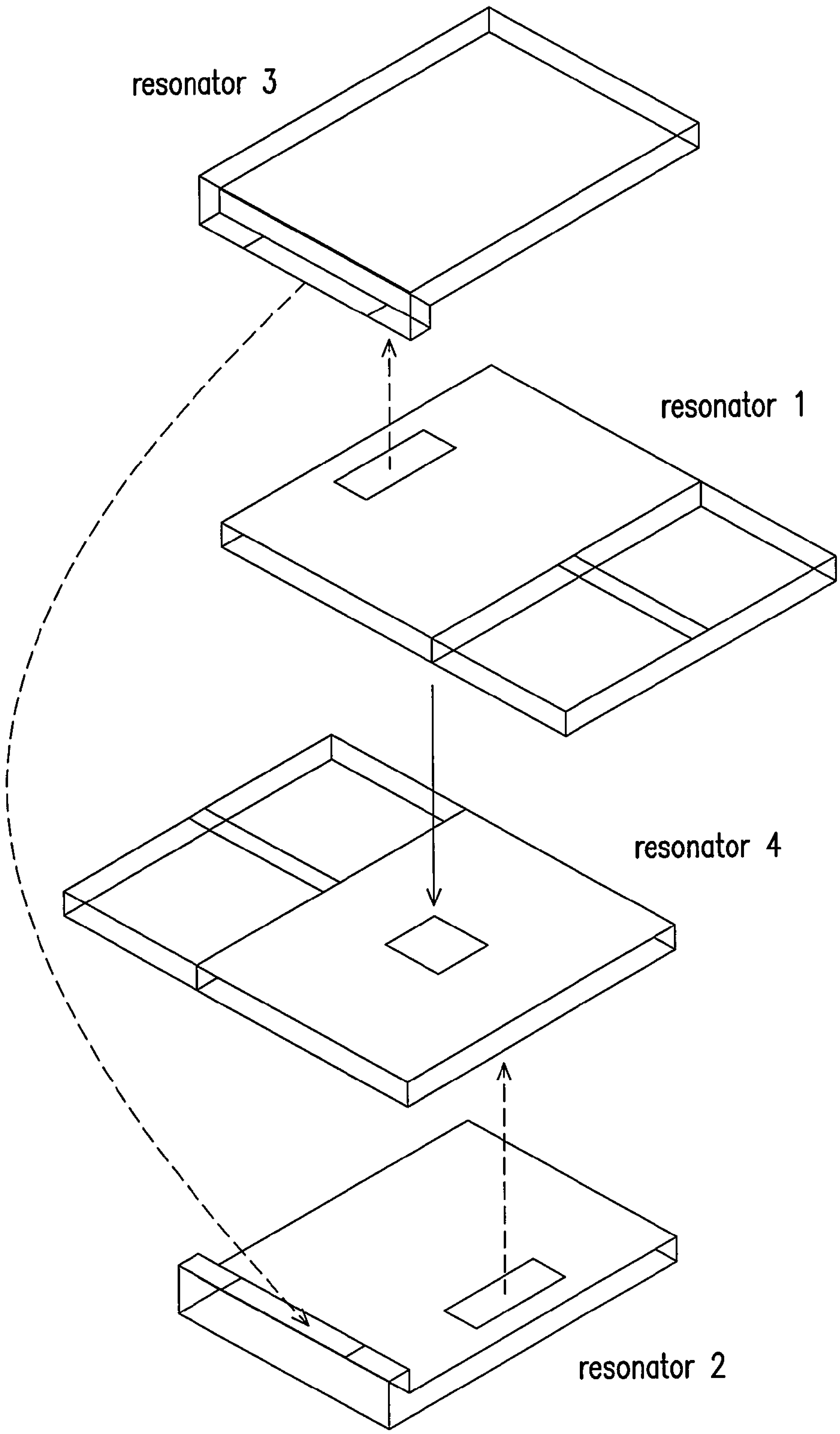

FIG. 19

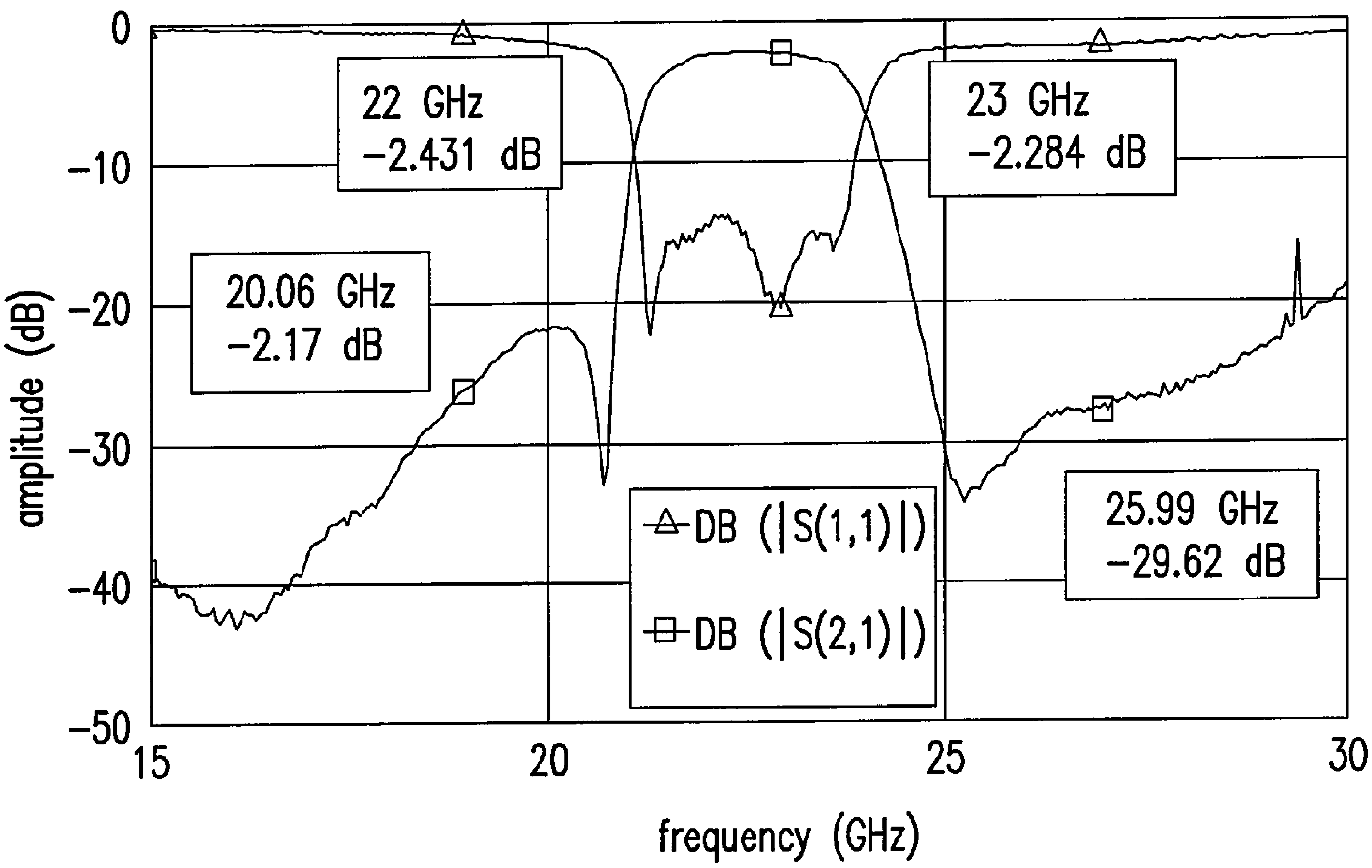
0
-10
-20
-30
-40
-50
amplitude (dB)
15
20
25
30
frequency (GHz)
22 GHz
-2.431 dB
23 GHz
-2.284 dB
20.06 GHz
-2.17 dB
25.99 GHz
-29.62 dB
DB (|S(1,1)|)
DB (|S(2,1)|)

FIG. 20

METHOD OF FORMING VERTICAL COUPLING STRUCTURE FOR NON-ADJACENT RESONATORS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of Taiwan application serial no. 96123207, filed on Jun. 27, 2007. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to a method of forming a coupling structure of resonators, and more particularly, to a method of forming a coupling structure of non-adjacent resonators.

2. Description of Related Art

In a wireless communication system, frequency selection elements, such as filters, duplexers, multiplexers and so on, are necessary key elements for radio-frequency front-end circuits. The frequency selection elements have functions for selecting or filtering/attenuating signals or noise in a specific frequency range in a frequency domain, so that rear-end circuits can receive signals in a correct frequency range and process the signals.

In the frequency ranges of microwave (1 GHz-40 GHz) and millimeter wave (40 GHz-300 GHz), the entire radio-frequency front-end circuits are formed of waveguide tubes in a large system. A waveguide tube has advantages of high-power endurance and extremely low loss, but its minimal size is limited because of its cut-off frequency. In addition, the waveguide tube is manufactured in non-batch method by precision work, and thus, high cost limits the application coverage of the waveguide tube.

Japanese Patent Application Laid-Open Publication No. 06-053711 provides a high-frequency signal transmission structure of an equivalent waveguide tube, which is formed by a circuit board structure. As shown in FIG. **1**, the structure is called as a substrate integrated waveguide (SIW), whose basic structure comprises a dielectric layer **3** and conductor layers **1** and **2**. The SIW structure has advantages of low-cost and integration with plane circuits since the SIW can be implemented by using a general circuit board or other multi-layered plane structures, such as low temperature cofired ceramic (LTCC), thereby. However, the SIW is formed of a multilayer board, thus its thickness is limited. Generally, the thickness is about several tens of mils, and the width is generally several hundreds of mils or more due to the restriction of the cut-off frequency (waveguide tube) or the resonant frequency (resonant cavity). The width-high ratio is usually greater than 10, and the width-high ratio for a conventional hollow waveguide tube is about 2. In comparison with the conventional waveguide tube, SIW with high width-high ratio may result in the following results. First, a flatter structure may result in higher metal-loss in the same width and the same transmission frequency, and therefore, the quality factor of the resonator is restricted. Second, in a flat structure, a number of resonators can be arranged in a vertical stack mode that occupies less area, so that the flat structure has advantages of small volume and high performance.

The coupling manner of a multi-stage resonator filter is related to the resonant mode and relative positions of the resonators. Nowadays, the staggered coupling manner using the SIW structure is to use a plane linear arrangement structure with an additional coupling mechanism, which is as shown in FIG. **2** (referring to X. Chen, W. Hong, T. Cui, Z. Hao and K. Wu, "Substrate integrated waveguide elliptic filter with transmission line inserted inverter", *Electronics Letter*, Vol. 41, issue 15, 21 Jul. 2005, pp. 851-852), a plane U-shape arrangement shown in FIG. **3** (referring to Sheng Zhang, Zhi Yuan Yu and Can Li, "Elliptic function filter designed in LTCC", *Microwave Conference Proceedings,* 2005. *APMC. Asia-Pacific Conference Proceedings*, Vol 1, 4-7 Dec. 2005) or a vertical U-shape arrangement shown in FIG. **4** (referring to Zhang Cheng Hao; Wei Hong; Xiao Ping Chen; Ji Xin Chen; Ke Wu; Tie Jun Cui, "Multilayered substrate integrated waveguide (MSIW) elliptic filter", *IEEE Microwave and Wireless Components Letters*, Vol. 15, Issue 2, Feb. 2005 Page(s): 95-97). For SIW structure, resonators in a linear arrangement are not efficient, and the additional coupling mechanism is too long which is disadvantageous for the multi-stage filter. Regardless of plane or vertical bending structure for the U-shape arrangement and taking a filter with four resonators as an example, the first resonator should be adjacent to the fourth resonator in order to form the staggered coupling structure. As a result, such structure limits the flexibility of arrangement of the input/output port, and occupies more areas.

In summary, in conventional techniques, there is no any technique that provides a vertically-staggered coupling structure for non-adjacent resonators. The conventional techniques limit the flexibility of the input/output port, and occupy more areas.

Additionally, for the design of current filters, a transmission zero (TZ) is formed by using the coupling between non-adjacent resonators in a main coupling path (that is, a staggered coupling). When the TZ is set at a proper frequency, a larger amount of signal attenuation can be obtained; that is, the same attenuation amount can be obtained by using fewer stages, so that the pass-band loss is lower, and the volume is smaller. However, as described above, there is no design to efficiently form coupling between non-adjacent resonators. Thus, it is necessary for those of skill in the art to provide an efficient staggered coupling structure for non-adjacent resonators.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a method of forming a coupling structure with vertically-stacked resonators, which is suitable for SIW structure. Such structure has the function for providing additional transmission zero points. The frequency selection elements with above characteristics have the advantages of low cost, small volume and good performance.

Accordingly, the present invention also provides a method of manufacturing a vertical coupling structure for non-adjacent resonators. A first and a second resonators are provided. The first and the second resonators respectively have a first and a second conductor surfaces, and the first conductor surface is opposite to the second conductor surface. At least one side edge of the first or the second resonator is used as the vertical coupling structure for the non-adjacent resonators. Then, a dielectric material layer is formed between the second conductor surfaces of the first and the second resonators. At least one first and one second high-frequency transmission lines are formed in a manner that the first high-frequency transmission line is configured at one side of the first conductor surface of the first resonator, and the second high-frequency transmission line is configured at one side of the first conductor surface of the second resonator. Then, at least one via pole is formed in a manner that the first high-frequency transmission line is vertically connected to the second high-frequency transmission line by the via pole.

In addition, the present invention also provides a method of manufacturing a vertical coupling structure for non-adjacent resonators. A first resonator is provided that at least one side of the first resonator is bent as a first bent extension structure, and a slot is formed on the first bend extension structure. Next, a second resonator is provided that the second resonator is not adjacent to the first resonator, and a slot is formed on the side of the second resonator opposite to the first bend extension structure of the first resonator. In this manner, the two sides may be electrically connected.

As described above, the present invention provides several coupling methods for cross layers when the resonators are vertically stacked. These methods are compliant with the existing multilayer substrate process, and can be easily designed and implemented. Therefore, the performance of the frequency selection element can be increased without adding cost.

These and other exemplary embodiments, features, aspects, and advantages of the present invention will be described and become more apparent from the detailed description of exemplary embodiments when read in conjunction with accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. **1** is a schematic diagram illustrating the high-frequency signal transmission structure of equivalent waveguide tubes formed by using circuit board structure in conventional techniques.

FIG. **2** is a schematic diagram illustrating a plane linear arrangement structure with additional coupling mechanism according to the conventional techniques.

FIG. **3** is a schematic diagram illustrating the coupling mechanism of the plane U-type arrangement according to the conventional techniques.

FIG. **4** is a schematic diagram illustrating the coupling mechanism of the vertical U-type arrangement according to the conventional techniques.

FIG. **5** is a schematic diagram illustrating a simplified circuit of a three-stage band-pass filter with staggered coupling structure according to one embodiment of the present invention.

FIG. **6** is a schematic diagram illustrating a simplified circuit of a four-stage band-pass filter with staggered coupling structure according to one embodiment of the present invention.

FIG. **7** is a schematic diagram illustrating the resonators formed by using a general substrate integrated waveguide.

FIG. **8** is a schematic diagram illustrating the resonator arrangement and the coupling mechanism in FIG. **6**.

FIG. **9** is a schematic diagram illustrating the resonator arrangement and the coupling mechanism of another four-stage band-pass filter with staggered coupling structure.

FIG. **10**A is a schematic diagram illustrating a coupling structure of non-adjacent resonators according to the first embodiment of the present invention.

FIG. **10**B is a side view illustrating the structure in FIG. **10**A, and FIG. **10**C is a front view illustrating the structure in FIG. **10**A.

FIG. **11** is a schematic diagram illustrating the coupling structure variations of FIG. **10**.

FIG. **12** is a schematic diagram illustrating another variation of FIG. **10**.

FIG. **13** is a schematic diagram illustrating another variation of FIG. **10**.

FIG. **14** is a schematic diagram illustrating another variation of FIG. **10**.

FIG. **15**A is a schematic diagram illustrating a coupling structure of non-adjacent resonators according to the second embodiment of the present invention.

FIG. **15**B and FIG. **15**C are schematic diagrams illustrating the process of forming bent extension structure.

FIG. **16**A is a schematic diagram illustrating a coupling structure variation of FIG. **15**A.

FIG. **16**B to **16**D are schematic diagrams illustrating coupling structure variations of FIG. **16**A.

FIG. **17** is a schematic diagram illustrating a configuration of a four-stage band-pass filter according to the present invention.

FIG. **18** is a schematic graph illustrating a frequency response of the S parameters for transmission and reflection (S**21** and S**11**, respectively) in FIG. **17**.

FIG. **19** is a schematic diagram illustrating a configuration of another four-stage band-pass filter according to the present invention.

FIG. **20** is a schematic graph illustrating a frequency response of S parameters for transmission and reflection (S**21** and S**11**, respectively) in FIG. **19**.

DESCRIPTION OF THE EMBODIMENTS

A band-pass filter circuit and its coupling mechanism will be described. FIG. **5** shows a simplified circuit configuration of a three-stage band-pass filter with staggered coupling structure according to one embodiment of the present invention. Referring to FIG. **5**, the structure comprises three resonators, two main coupling mechanisms (M**12**, M**23**) and one weak staggered coupling mechanism (M**13**). The polarities of the coupling mechanisms Map (α, β=1, 2, 3, $\alpha \neq \beta$) are defined as that the polarity for the magnetic field coupling is positive, and the polarity for the electric field coupling is negative. In this case, if M**12**, M**23** and M**13** are all magnetic field couplings, a transmission zero is formed at a frequency lower than the pass band. If M**12** and M**23** are magnetic field couplings and M**13** is an electric field coupling, a transmission zero is formed at a frequency higher than the pass band. In order to comply with different specifications, the coupling types between resonators can be varied, so that the transmission zero can be set at a proper frequency.

FIG. **6** shows a simplified circuit configuration of a four-stage band-pass filter with staggered coupling structure according to another embodiment of the present invention. As shown in FIG. **6**, the structure comprises four resonators, three main coupling mechanisms (M**12**, M**23** and M**34**) and one weak staggered coupling mechanism (M**14**). Here, the polarities of the coupling mechanisms M$\alpha\beta$ (α, β=1, 2, 3, 4, $\alpha \neq \beta$) are also defined in the same way. The polarity for the magnetic field coupling is defined as positive, and the polarity for the electric field coupling is defined as negative. In this case, if M**12**, M**23** and M**34** are magnetic field couplings, and M**14** is an electric field coupling, there are two transmission zeros respectively at the high-frequency end and the low-frequency end of the pass-band frequency. If M**12**, M**23**, M**34** and M**14** are all magnetic field couplings, there is no transmission zero.

FIG. **7** schematically shows resonators of a general substrate integrated waveguide (SIW) type. Generally, most of the SIW resonator structures have cubic geometric structure. As shown in FIG. **7**, the size in Y-direction is much smaller than the size in X-direction and Z-direction. For most conditions, the SIW type resonators are operated at TE 101 mode. In the TE 101 mode, since no significant variation in the electromagnetic field is occurred at the Y-direction, the electromagnetic field can be treated as being distributed on the XZ-plane. The electric field at the center of the XZ-plane is strongest, and the magnetic field at the edges of the XZ-plane is strongest. If it is necessary to form an effect of an electric field coupling for adjacent two resonators in the Y-direction, an opening can be formed at the center of the XZ-plane. In addition, if it is necessary to form an effect of a magnetic field coupling for adjacent two resonators in the Y-direction, an opening can be formed at the edges of the XZ-plane.

FIG. **8** is a schematic view illustrating the resonator arrangement and the coupling mechanism in FIG. **6**. As shown in FIG. **8**, the filter circuit has four-stage band-pass filters with staggered coupling structure, and comprises four resonators **1** to **4**. Each of the four resonators **1** to **4** comprises one or more layered medium (dielectric) substrate, two adjacent resonators are separated by a metal surface (not shown). The four resonators **1** to **4** are vertically stacked, and a slot is formed on the separation metal surface (not shown, referring to the following embodiments) so as to form coupling structures (M**12**, M**23** and M**34**). The position of the slot can be properly selected to form an electric field coupling structure or a magnetic field coupling structure. For example, forming the slot at the center position can create an electric field coupling effect, while forming the slot at the edge position can create the magnetic field coupling effect.

In the embodiment shown in FIG. **8**, the coupling between the resonator **1** and the resonator **4** is a staggered coupling. Because the two resonators **1** and **4** are not adjacent, it is not impossible to form a coupling structure by forming a slot in the metal layer that separates adjacent resonators. FIG. **10** to FIG. **14** show several exemplary structures for such staggered coupling structure to explain the staggered coupling (M**14**) between the resonators **1** and **4**.

FIG. **9** is a schematic diagram illustrating the resonator arrangement and the coupling mechanism of a four-stage band-pass filter with staggered coupling structure. The arrangement order and the positions of input/output ports for the resonators in FIG. **9** are different from those in FIG. **8**. As shown in FIG. **9**, the resonator **2**, the resonator **1**, the resonator **4** and the resonator **3** are arranged sequentially from top to bottom. The input port is connected to the resonator **1**, and the output port is connected to the resonator **4**. In the four-stage band-pass filter, the main signal coupling path is: the resonator **1**=>the resonator **2**=>the resonator **3**=>the resonator **4**, in which the coupling between the resonator **2** and the resonator **3** (M**23**) is the coupling for non-adjacent resonators, and the coupling between the resonator **1** and the resonator **4** (M**14**) is the staggered coupling.

First Embodiment

In order to achieve the coupling mechanism as shown in FIG. **8**, the present invention provides a connection structure of a vertical staggered coupling for non-adjacent resonators. FIG. **10**A is a schematic diagram illustrating a coupling structure for non-adjacent resonators according to the first embodiment of the present invention. FIG. **10**B is a side view of the structure in FIG. **10**A, and FIG. **10**C is a front view illustrating the structure of FIG. **10**A. In FIG. **10**A, FIG. **10**B and FIG. **10**C, resonators between the non-adjacent resonators are omitted. Hereinafter, the upper and the lower resonators are used as an example for representing the resonators **1** and **4** in FIG. **8** respectively.

As shown in FIG. **10**A, FIG. **10**B and FIG. **10**C, a resonator **100** (equivalent to the resonator **1**) comprises a first metal layer (surface) **102**, a dielectric layer **108** and a second metal layer (surface) **106**. The dielectric layer **108** can be a multilayer structure, and the layer number of the dielectric layer **108** is not limited. Also, a resonator **150** (equivalent to the resonator **4**) comprises a first metal layer **152**, a dielectric layer **158** and a second metal layer **156**. The dielectric layer **158** can a multilayer structure, and the layer number of the dielectric layer **158** is not limited.

The staggered coupling mechanism M**14** as shown in FIG. **8** can be formed between the resonator **100** and the resonator **150**, the two resonators are not adjacent. Other resonators can be further arranged between the resonator **100** and the resonator **150**, and the dielectric layer is filled between the resonators. The embodiment focuses on the connection structure of staggered coupling mechanism between the resonator **100** and the resonator **150**, the detailed structure between resonator **100** and **150** can be properly modified by those skilled in the art. Ignoring the omitted structure, the second metal layer **106** of the resonator **100** is opposite to the second metal layer **105** of the resonator **150**.

As shown in FIG. **10**A, a slot **103** is formed at the side edge of the first metal layer **102** of the resonator **100**, and a high-frequency transmission line (hereinafter, referred to as transmission line) **104** is extended from the slot **103**. In addition, a slot **153** is formed at the side edge of the first metal layer **152** of the resonator **150**, and a transmission line **154** is extended from the slot **153**. Basically, the position of the transmission line **104** is opposite to the position of the transmission line **154**, that is, the transmission lines **104** and **154** are at the vertically projected position of each other. The transmission line **104** is electrically connected to the transmission line **154** by a via pole **178** so as to form the staggered coupling structure. In order to connect the transmission lines **104** and **154** by the via pole **178**, slots **106***a* and **156***a* can be further respectively formed at the second metal layer **106** of the resonator **100** and the second metal layer **156** of the resonator **150**, so that the via pole **178** can be extended from the transmission line **104** of the resonator **100**, penetrated through the slot **106***a* of the resonator **100** and the slot **156***a* of the resonator **150**, and then connected to the transmission line **154**. The detailed structure is shown in FIGS. **10**B and **10**C. In addition, via poles **172** and **174** can be further formed between the metal layer **106** and the metal layer **156** to electrically connect the two second metal layers **106** and **156**, and the detailed structure thereof is shown in FIG. **10**C.

Regarding the manufacturing process, the ordinary printed circuit board (PCB) process can be adapted for making the coupling structure. That is, stacked layers of dielectric layers and metal layers can be formed, and then a specific pattern or slot is further formed on each of the metal layers. The dielectric layers are drilled and then filled with metal material to form the via pole.

In the embodiment, the transmission lines **104** and **154** are formed by using microstripe lines, and connected through the via pole to same structure that is extended from the upper and lower resonators **100**, **150**. In this way, a high-frequency signal can be transmitted between two non-adjacent resonators.

FIGS. **11** to **14** are schematic diagrams illustrating the coupling structures of non-adjacent resonators of variations of FIG. **10**. FIG. **11** is a schematic diagram illustrating a coupling structure of non-adjacent resonators according to another embodiment of the present invention. FIG. **10** and FIG. **11** have the same function, but slightly different to each other in their structures. The difference between FIGS. **10** and **11** is the shape of the slot formed on the metal layer. As shown in FIG. **11**, a slot **114** is formed at the edge of the metal layer, and substantially in a T shape. If the size of the slot in FIG. **11** is made larger, the efficiency of coupling can be further increased.

The other portion of the coupling structure in FIG. **11** is the same as those in FIG. **10**, and the detailed description is omitted.

FIG. **12** is a schematic diagram illustrating a coupling structure of non-adjacent resonators according to another embodiment of the present invention. The structure of the transmission line in FIG. **12** is different from that in FIG. **10** or FIG. **11**. FIGS. **10** and **11** show a structure that an open slot formed at the edge of the metal layer and the transmission line is extended from the slot. FIG. **12** shows a slot **124** that is formed at the edge of the metal layer and is a closed slot, and a transmission line is formed on the slot **124**. The transmission lines of the two resonators are also connected by a via pole to effect transmitting high-frequency signals.

FIGS. **13** and **14** are schematic diagrams illustrating coupling structures of non-adjacent resonators according to other embodiments of the present invention, in which a microstripe line is coupled to a resonator by a current probe. As shown in FIG. **13**, basically differing from the structure in FIG. **10**, a transmission line **192** is isolated from a metal layer (corresponding to the first metal layer **102** in FIG. **10**) by a slot **190**, and one end of the transmission line is connected to another metal layer of the resonator (corresponding to the first metal layer **106** in FIG. **10**) by a current probe **194**, while the other end of the transmission line is also connected to the transmission line of the lower resonator. FIG. **14** also shows a coupling structure of non-adjacent resonators with a current probe. The difference is in that FIG. **13** shows a structure of the transmission line and the resonator being formed on the same layer, while FIG. **14** shows a structure of the transmission line being disposed over the metal layer of the resonator.

In the above structures shown in FIGS. **10** to **14**, the coupling phase can be adjusted by changing the length of the transmission line. In addition, the transmission line can be any applicable structure, such as a microstripe line, a stripe line, a coplanar waveguide, a slot line, a coaxial line or a waveguide tube and so on.

Second Embodiment

FIG. **15**A is a schematic diagram illustrating a coupling structure of non-adjacent resonators according to the second embodiment of the present invention. In the embodiment, the coupling structure is formed by a bent extension structure of the resonator. As shown in FIG. **15**A, two side edges of a resonator **200** are formed as bent extension structures **200***a* and **200***b*. In addition, a slot **200***c* is formed in the extension structure **200***a*, and another slot (not shown) is also formed in the extension structure **200***b*. Likewise, two side edges of a resonator **202** are formed as bent extension structures **202***a* and **202***b*, and slots **202***c* and **202***d* are respectively formed in the extension structure **202***a* and **202***b*. Next, the bent extension structures **200***a* and **200***b* of the upper resonator **200** are respectively connected to the bent extension structures **202***a* and **202***b* of the lower resonator **202** to form a dual-side coupling structure as shown at the right of FIG. **15**A. In the embodiment, the magnetic coupling structure is formed by forming the slots (for example, **200***c* and **202***c*) in the longitudinal metal surfaces contacted to the resonators **200** and **202**.

The method of forming the bent extension structure as shown in FIG. **15**A will be described with reference to FIGS. **15**B and **15**C. A stack structure of metal layers **201***a*, **201***b*, **201***c* and a dielectric layer **203** is formed, so as to form a resonator **200**. As shown in FIG. **15**C, plural openings are formed at the left side of the resonator **200**, and then the openings are filled with metal materials to form via poles **204** and **206**. By forming different heights of the via poles **204**, **206**, and the bent extension structures **200***a*, **200***b*, **202***a* and **202***b* are formed.

FIG. **16**A is a schematic diagram showing a variation of the coupling structure of FIG. **15**A. The coupling structure shown in FIG. **15**A is a dual-side coupling structure, and the coupling structure shown in FIG. **16**A is a single-side coupling structure. That is, in FIG. **16**A, only one bent extension structure **210***a* is formed at the edge of a resonator **210**, and a slot **210***b* is formed in the bent extension structure **210***a*. Likewise, only one bent extension structure **212***a* is formed at the corresponding edge of a resonator **212**, and a slot **212***b* is formed in the bent extension structure **212***a*, where the slot **210***b* is opposite to the slot **212***b* so as to form the magnetic coupling structure.

FIGS. **16**B-**16**D are schematic diagrams showing several variations of the single-side coupling structure of FIG. **16**A. In FIG. **16**B, the bent extension structure is only formed at one edge of the lower resonator, and the upper resonator is still a planar resonator. In FIG. **16**C, the bent extension structure is only formed at one edge of the upper resonator, and the lower resonator is still a planar resonator. FIG. **16**D shows a structure that the bent extension structure is formed at one edge of the upper resonator, and the bent extension structure is also formed at another edge of the lower resonator, where the bent extension structures of the upper and lower resonators are combined together. The method of manufacturing the bent extension structures in FIGS. **16**A to **16**D is similar to FIGS. **15**B to **15**C.

FIG. **17** is a schematic diagram showing a structure of a four-stage band-pass filter according to the present invention. The coupling structure for non-adjacent resonators in the four-stage band-pass filter will be described with reference to the embodiment shown in FIG. **10**. FIG. **18** is a schematic graph showing a frequency response of S parameters for transmission and reflection (S**21** and S**11**, respectively) in FIG. **17**. From top to bottom in FIG. **17**, the upmost resonator and the lowermost resonator are formed as a non-adjacent coupling structure. A LTCC structure is adapted for the above filter, where the LTCC structure comprises 16 layers and has a thickness of 2 mils for each layer. The loss tangent of the LTCC material is about 0.0075, the dielectric constant is about 7.8, and the plane size of the filter is less than 145 mil×179 mil. The center frequency is 29.5 GHz, the bandwidth is 3.93 GHz, the pass-band loss is less than 2.8 dB, and there are two transmission zeros TZ**1** and TZ**2** respectively disposed at the two sides of the pass-band frequency band.

FIG. **19** is a schematic diagram illustrating a four-stage band-pass filter that is implemented by using the non-adjacent resonator coupling structure shown in FIG. **15**. FIG. **20** is a schematic graph illustrating a frequency response of S parameters for the transmission and reflection (S**21** and S**11**, respectively) in FIG. **19**.

The main coupling paths for the four-stage band-pass filter in FIG. **19** are magnetic couplings (shown in dotted line), including a coupling of non-adjacent resonators. The staggered coupling is achieved by forming slots on the metal surfaces of the resonators land **4**. Since the electric field is strongest in the slot, the staggered coupling is an electric field coupling. In this way, two transmission zeros are respectively formed at the two sides of the pass-band frequency band. A LTCC structure is adapted for the filter. The LTCC structure has 16 layers, and each layer has a thickness of 2 mils. The loss tangent of the LTCC material is about 0.0075, the dielectric constant is about 7.8, and the plane size of the filter is less than 140 mil×160 mil. As shown in FIG. **20**, the measured center frequency is 22.5 GHz, the bandwidth is 1 GHz, and the pass-band loss is less than 2.5 dB.

In summary, the present invention provides several coupling methods for cross layers when the resonators are vertically stacked. These methods are compilable comply with the existing multilayer substrate process, and can be easily designed and implemented. Therefore, performance of the frequency selection element can be increased without adding cost.

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A method of manufacturing a vertical coupling structure for non-adjacent resonators, comprising:

providing a first and a second resonators, respectively having a first and a second conductor surfaces, wherein the first conductor surface is opposite to the second conductor surface, and at least one side of the first or the second resonator is used as the vertical coupling structure for the non-adjacent resonators;

forming a dielectric material layer between the second conductor surfaces of the first and the second resonators;

forming at least one first high-frequency transmission line and one second high-frequency transmission line, wherein the first high-frequency transmission line is configured at a side of the first conductor surface of the first resonator, and the second high-frequency transmission line is configured at a side of the first conductor surface of the second resonator; and

forming at least one via pole, vertically connected to the first and the second high-frequency transmission line.

2. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, wherein the first or the second high-frequency transmission line is formed by using one of a microstripe line, a stripe line, a coplanar waveguide, a slot line, a coaxial line or a waveguide tube.

3. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, further comprising: adjusting a length of the first or the second high-frequency transmission line according to a phase of the coupling.

4. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, wherein the first and the second resonators are a substrate integrated waveguide (SIW) resonator.

5. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **4**, wherein the SIW resonator is formed by a multilayer substrate process.

6. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, further comprising: forming a slot at the side of each of the first conductor surfaces of the first and second resonators, wherein each of the first and second high-frequency transmission lines is extended by a predetermined length from the slot.

7. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, further comprising: forming a recessed slot at the side of each of the first conductor surfaces of the first and second resonators, wherein each of the first and second high-frequency transmission lines is disposed over the corresponding slot and extended a predetermined length from the slot.

8. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, further comprising: forming a slot at the side of each of the first conductor surfaces of the first and second resonators, wherein one end of each of the first and second high-frequency transmission lines is disposed over the corresponding slot and extended by a predetermined length from the slot.

9. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **8**, further comprise: forming a current probe, penetrating the slot through the via pole and connected to the second conductor surface.

10. The method of manufacturing a vertical coupling structure for non-adjacent resonators according to claim **1**, wherein the first and second conductor surface are a metal surface.

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